ECOLOGY OF WINYAH BAY, SOUTH CAROLINA, AND POTENTIAL IMPACTS OF ENERGY DEVELOPMENT

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PREFACE

An estuary is defined as a semienclosed coastal basin in which freshwater runoff is mixed with seawater. Superimposed on the pattern of tidal movements of water toward and from the ocean is the discharge of freshwater into the estuary from terrestrial sources. The result is a physically complex environment. At any location within an estuary, tidal amplitude, current direction and velocity, temperature, salinity, turbidity, nutrient concentrations and many other physical and chemical properties of the water column change over time. Relatively large lateral and vertical fluctuations in environmental parameters occur on tidal, diurnal, and seasonal time scales.

Estuarine organisms are more tolerant of large and irregular fluctuations in environmental factors than freshwater and open ocean organisms. Few species are adapted to live under such stressful conditions and, typically, estuaries are populated by high densities of relatively low numbers of species. One species of grass, *Spartina alterniflora*, completely dominates high salinity estuarine marshes from the maritime provinces of Canada to northern Florida. Because of the abundance and photosynthetic capabilities of this plant, *Spartina* marshes are among the most productive ecosystems on Earth. Benthic algae and phytoplankton also contribute to to the high productivity of estuaries.

Estuarine animals are dependent on the production of proteins, sugars, and other organic materials by plants; however, the majority of invertebrates do not feed directly on green plants. Decomposing marsh grasses and other vegetation (detritus) form the basis of the food web in estuaries. Filter feeders such as oysters, clams and planktonic crustaceans, derive their energy from microscopic organic particles and phytoplankton. Scavengers such as shrimp or crabs consume larger detrital particles which accumulate on the bottom. Many predators, especially fishes, inhabit estuaries, and most have generalized diets which enable them to consume whatever prey items are available. The estuarine food web is complex and, although estuarine ecologists have learned a great deal in the last decade, much more research is needed before the interactions between various types of organisms are understood.

One aspect of estuaries that has great implications for society is the production of commercially valuable populations of shrimps, crabs and fishes. Some of these species complete their entire life cycles within the estuaries, but the adults of most species live and reproduce in the ocean. Larval shrimps and fishes migrate into estuarine areas where abundant food supplies are available. The significance of estuaries as nursery areas cannot be overemphasized, and there is little doubt that without healthy estuaries, the commercial fisheries would disappear.

Winyah Bay is not only one of the largest estuaries in the southeast, it has some characteristics which make it unique. Few other estuaries are almost completely bordered by marshes. No other estuary is surrounded with so much land that has been set aside, in perpetuity, for the purpose of research, education and conservation (The Belle W. Baruch Foundation's

Hobcaw Barony and the Thomas Yawkey Wildlife Center). Few other estuaries have such large populations of endangered or threatened species (e.g. shortnose sturgeon, brown pelican, bald eagle, sea turtles).

The vast size and dynamic nature of Winyah Bay renders any comprehensive ecological investigation of physical, chemical, and biological characteristics of the estuary an impossible task. Our two-year study of the ecology and potential impact of petroleum on the estuary was designed to provide basic ecological information which would constitute a framework from which potential impacts could be predicted. This report summarizes the results of the first year of that study.

The initial field study concentrated on the two major creeks which exchange water and materials between the Mud Bay section of Winyah Bay and the North Inlet salt marsh. The sampling program consisted of nine intensive 24-hour cruises at No Man's Friend and South Jones Creeks every six weeks, plus an additional nine shorter cruises between the major cruises. Nine Winyah Bay cruises in the first year provided information from six stations located between the ocean and freshwater extremes of the estuary. Hundreds of hours of field measurements and collections and thousands of hours of laboratory and computer analysis have resulted in a massive data base and an initial understanding of the basic ecological processes of the system.

The data presented in this volume represent only the first level of analysis. Seasonal trends are essential to the characterization of any ecosystem, and temporal variations on this level are described and discussed with respect to the various locations sampled in Winyah Bay. Short term (daily and hourly) variations in the physical characteristics, chemistry, and abundance of organisms represent a more specific level of information about estuarine dynamics. These tidal and diel fluctuations will be the subject of several manuscripts which will be published in the scientific literature at a later date.

A one year study of any ecosystem, especially one as complex as an estuary, provides only a passing glimpse of a long-lived and very dynamic entity. Annual fluctuations in freshwater input, for instance, could radically change the character of the locations which were sampled the previous year. Nevertheless, the information gathered in this study has filled a tremendous void. Data from No Man's Friend and South Jones Creeks will become part of another even larger effort by the Belle W. Baruch Institute of the University of South Carolina to document and analyze long-term changes in the North Inlet salt marsh. An understanding of natural fluctuations and long-term trends in an undisturbed ecosystem such as North Inlet is essential if scientists are going to be able to predict the effects of natural and man-induced perturbations on such ecosystems.

Studies during the second year are focused on the six original Winyah Bay stations plus five additional ones. This network of sampling sites represents each of the major subtidal habitat types within the estuary. Emphasis has been placed on the early life stages (eggs, larvae, and young) of crustaceans, especially shrimps and crabs, and fishes. Spatial and temporal variations in abundance will be correlated with measurements of the physical and chemical characteristics to provide information on the utilization of the estuary by young organisms. The susceptibility and vulnerability of larval stages to petroelum pollution in Winyah Bay will be discussed in light of these studies.

This report has been written for scientific accuracy, but in a style which, hopefully, can be useful to non-scientists. A description of the study area and methods is followed by chapters which discuss each of the major sets of measurements that were taken. Another chapter summarizes the data from the first year cruises in Winyah Bay. The potential impacts of energy related industry, especially petroleum, are discussed in the final chapter. Over the last decade the enormous amount of money and time spent by governments and industries of the world on studies of the effects of oil in aquatic ecosystems has resulted in thousands of documents. It is beyond the scope of this project to review all of this literature; however, our assessment of the potential impact of oil in Winyah Bay estuary is based on our first-hand knowledge of estuarine ecology and opinions generated from the reading of hundreds of scientific studies conducted in similar ecosystems. We believe this assessment constitutes an initial attempt toward understanding the fundamental problems associated with the acute and chronic pollution of an estuary by petroleum.

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EXECUTIVE SUMMARY

1. We conducted an intensive study of the physical, chemical, and biological characteristics of Winyah Bay, especially those creeks which exchange water and materials with North Inlet. The results of these studies are discussed with respect to the potential effects of energy related development in the estuary.

2. Phytoplankton production was highest from June through September when water temperatures were high, vertical visibility in the water column was low, concentrations of total nitrogen and total phosphorous were at their highest levels, and concentrations of nitrate-nitrite and orthophosphate were at low levels. High chlorophyll *a* and phaeopigment concentrations during summer indicated maximum production and turnover rates for the year occur during the warm months. Phytoplankton populations would be expected to experience initial adverse impacts after exposure to spilled oil. Recovery to near normal levels would be expected after toxic soluble fractions were dispersed.

3. Rooted marsh plant populations which almost completely surround Winyah Bay would probably be severely impacted by an oil spill. Hundreds of acres of *Spartina* marsh could be eliminated by a spill. Recovery would be very slow because of the inhibition of seed germination and the persistance of oil in marsh muds for at least a decade. Marsh grasses exposed to constant low level discharges of oil and grease from refinery effluents would be adversely effected.

4. Zooplankton composition and abundance in Winyah Bay was similar to other Southeast coastal systems. Permanent members of this diverse microscopic community were mostly herbivorous copepods. Temporary members of the zooplankton included eggs and larvae of most crabs, shrimps, shellfishes, fishes, and many less familiar invertebrates. Diversity and abundance was highest in summer for most species, especially larvae. Acute poisoning from an oil spill would destroy sensitive early life stages and could eliminate a single year's reproductive effort by commercially important crustacean, mollusc, or fish populations. Copepods would probably repopulate the area rapidly. Long term exposure to low concentrations of oily residues and effluents could have more subtle sublethal effects on some organisms.

5. Mysid shrimps, amphipods, and other less familiar small crustaceans, which constitute major food sources for juvenile fishes, live near or on the bottom and are permanent members of the motile epibenthos. Most late larval and juvenile crabs, shrimps, and fishes also live close to the bottom of marsh creeks and estuarine areas. Since non-soluble oil droplets adhere to suspended sediments and accumulate on the bottom, the potential impact of an oil spill or chronic discharges of petroleum compounds on animal populations which live, feed and reproduce near the bottom is likely to be serious. Damage to permanent and temporary members of the motile epifauna would affect

the entire estuarine food web. Non-motile benthic communities are particularly susceptible to damage by polluted sediments.

6. Adult shrimps, crabs, and fishes constitute major commercial and recreational resources in Winyah Bay. Larval stages are usually most sensitive to oil pollution; however, polluted estuarine areas could inhibit migration patterns, feeding, growth, reproduction and other activities of juveniles and adults. Long-term effects of oil pollution on these populations may result in lower availability, and seafood may become tainted and contain compounds carcinogenic to man.

7. Winyah Bay and its surrounding wetlands support some of the highest densities of nesting wading birds and migrating waterfowl in the region. Endangered and threatened bird, reptile, fish, and mammal populations presently inhabit the estuary. All are susceptible to acute and chronic oil pollution.

8. Winyah Bay, one of the largest estuaries in the Southeast, exchanges water and materials with pristine North Inlet, site of one of the world's most active estuarine research programs, and with the Santee system, which is about to be radically altered by rediversion. We are lacking information on the extent to which Winyah Bay Estuary is already stressed by industrial, agricultural, and domestic inputs. The inevitable degradation of water quality associated with an oil refinery would have negative local, regional and national repercussions.

CHAPTER 1. DESCRIPTION OF THE STUDY AREA

No Man's Friend Creek (NMF) and South Jones Creek (SJ) are relatively shallow marsh waterways which connect two hydrographically distinct estuarine ecosystems (Fig. 1-1). Haulover Creek is the only other waterway connecting Winyah Bay and North Inlet, but it is so narrow and shallow that water flow is restricted to within a few hours of high tide.

The creeks meander through marshes which are dominated by saltmarsh cordgrass (*Spartina alterniflora*). Areas of the marsh surface which are slightly higher in elevation with respect to high tide are vegetated by big cordgrass (*Spartina cynosuroides*) and black needle rush (*Juncus roemerianus*). High marsh flats and edges are characterized by saltmeadow hay (*Spartina patens*), several species of glass worts (*Salicornia spp.*), salt grass (*Distichlis spicata*), sea oxeye (*Borrichia frutescens*) and sea lavender (*Limonium carolinianum*). A transitional shrub community composed of marsh elder (*Iva frutescens*) and southern red cedar (*Juniperus silicola*) border portions of SJ, especially near Collins Island. A maritime forest dominated by loblolly pine *(Pinus taedo)* and live oak *(Quercus virginiana)* is located on the island.

With the exception of the several hundred meter interface of SJ and Collins Island, the creeks are bordered by steep marsh banks. Only narrow muddy intertidal slopes fringe the marsh banks. More extensive in-

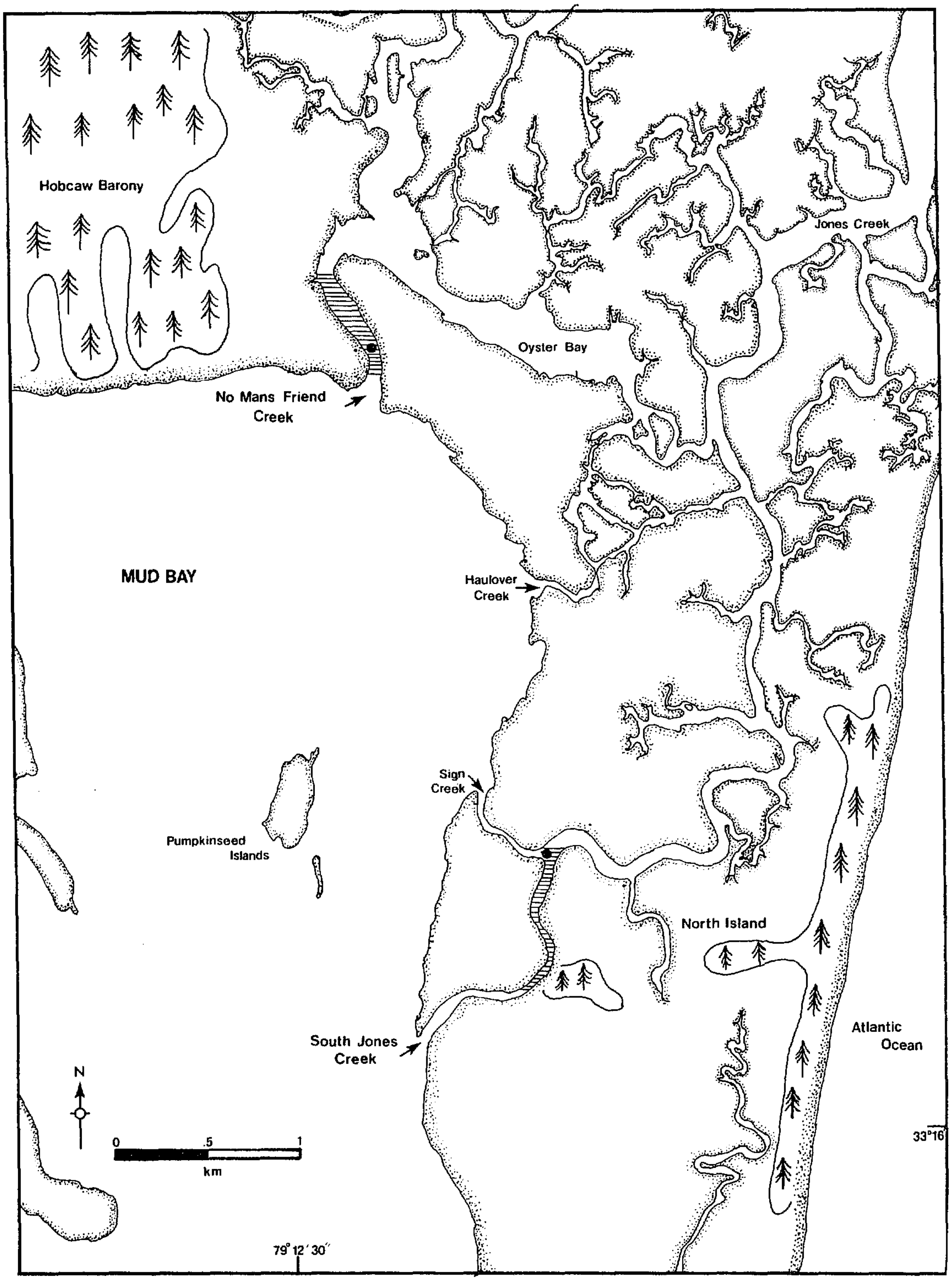


Figure 1-1. Map of Mud Bay section of Winyah Bay showing sampling sites at No Man's Friend and South Jones Creeks. The dark circles indicate the stationary measurements and water sample collection stations. The hatched zones indicate the area in which all net collections were made.

tertidal mudflats are located at the intersection of NMF and Mud Bay; large flats also occur at the mouths of SJ and Sign Creeks.

The subtidal substrate at NMF consists of a layer of fine organic sediments over a more firm muddy-sand base. Subtidal populations of macroalgae, especially sea lettuce (*Ulva lactuca*), occur from November through May. Sponges, gorgonians (soft corals), and other sessile benthic organisms characteristic of nearby creek bottoms in North Inlet do not occur in NMF. Only small and isolated clusters of low intertidal oysters (*Crassostrea virginica*) were observed. Preliminary bucket dredge tows and S.C.U.B.A. collected benthic box cores indicated that a low diversity of macroinvertebrates occurred in NMF. The soft clam (*Macoma baltica*) was the most conspicuous bivalve mollusc and few large polychaetes were found.

Although the sediment character of SJ and NMF is similar, the bathymetry of the two creeks is very different. On the North Inlet side of the South Jones Creek sampling platform, intertidal oyster bars border the creek banks and form islands which are surrounded by soft mud sediments at low tide. The platform is situated in a basin at the convergence of South Jones and Sign Creeks (Fig. 1-1). The creek bottom in SJ and Sign Creeks between the basin and Winyah Bay is muddy sand. Generally, the bottom topography is more irregular at SJ than NMF and larger accumulations of root masses, *Spartina* stalks, and tree branches occur at SJ. Vascular plant detritus (decomposing plant material) was usually more abundant in net collections at SJ. No sponges and gorgonians were collected, but fairly well developed subtidal oyster populations were found. Benthic macroalgae and fouling epibenthic organisms (e.g. bryozoans, barnacles, hydroids) were more abundant in SJ than NMF. Detailed benthic studies were not conducted, but preliminary dredgings and dives indicated that the benthic infauna was similar to that collected in NMF.

The physical, chemical and biological characteristics of NMF and SJ Creeks are influenced by tidal exchange between North Inlet and Winyah Bay. Kjerfve (1978) estimated that 80% of the exchange between the two systems occurs through SJ. The relationship between connecting creeks and adjacent estuaries has been examined at SJ and other similar systems (Pritchard, 1960; Pritchard and Gardner, 1974; Bowman, 1976; Van de Kreeke, 1978).

North Inlet salt marsh is one of the most intensively studied salt marsh ecosystems in the world. It is a bar-built class C type estuary (Pritchard, 1955), which exchanges coastal waters through a wide and shallow inlet. Hydrographic characteristics include a salinity range of 30-34 parts per thousand (o/oo), average channel depth of 5 m, and a semi-diurnal tide with a maximum spring range of 2.5 m and a neap range of approximately 1.0 m (Kjerfe, 1978). Water quality in North Inlet is excellent and shellfish harvesting is approved (South Carolina Department of Health and Environmental Control, 1977; South Carolina Pollution Control Authority, 1972). Annual freshwater input into the North Inlet marsh is low because of the relatively small drainage basin (T. Williams, Baruch Forest Science Institute, personal communication).

The hydrographic characterization of NMF and SJ conducted in this study was based on hourly measurements of salinity, temperature and depth. Details of these physical measurements are given in Chapters 2 and 3.

Hydrographic data was collected from a stationary boat at SJ adjacent to Sign Creek (33°16'53"N, 79°11'32"W) and in midchannel at NMF near Mud Bay (33°18'12"N, 79°11'32"W) (Fig. 1-1).

Ten complete ebb tides were observed in NMF. The ebb tide lasted an average of 6.9 hours (5-9 hours). The direction of the ebb tide was initially toward Winyah Bay for 2-5 hours (mean=3.8 hours). During this period, surface salinity increased and bottom salinity increased or remained unchanged. Salinity of surface water was less than or equal to bottom salinity. At the conclusion of the Winyah Bay directed ebb tide, large portions of Mud Bay were exposed and only minimal surface flow occurred. The direction of the remainder of the ebb tide was toward North Inlet and lasted 2-4 hours (mean=3.1 hours). During this period, surface salinity typically decreased or remained stable. Recorded surface salinities were less than or equal to bottom salinities.

Eight of the thirteen flood tides observed at NMF were directed toward North Inlet. The flooding tide toward North Inlet lasted an average of 4.6 hours (3-6 hours). Surface salinity usually decreased or remained unchanged and bottom salinity always decreased or remained unchanged. Surface salinities were less than or equal to bottom salinities.

The five flooding tides directed toward Winyah Bay averaged 5.0 hours in length (4-7 hours). Surface salinity always increased and bottom salinity increased or remained unchanged. Recorded surface salinities were less than or equal to bottom salinities.

The direction of the flooding tide at NMF appeared to be related to tidal amplitude. During periods of tidal flooding toward Winyah Bay, tidal amplitude averaged 1.46 m and varied from 1.2 m to 1.7 m. Tidal amplitudes were much greater during periods of tidal flooding toward North Inlet, averaging 1.86 m with a range of 1.4 m to 2.1 m. Only two instances were observed in which tidal amplitude was low (1.4 m) and tidal flooding was directed toward North Inlet. In both cases, strong southwesterly (or south-southwesterly) winds prevailed and wind speeds averaged 5.8 mph or 11.5 mph. Generally, unless complicated by strong southerly winds, flooding at NMF was directed toward Winyah Bay during periods when tidal amplitudes were low (<1.75 m) and toward North Inlet when tidal amplitudes were high (≥1.75 m).

Thirteen complete ebb tides were studied at SJ. Ebb tides averaged 5.5 hours (4-7 hours). All ebb tides were directed toward Winyah Bay. During the ebb tide, surface salinity either increased (7 times) or decreased (6 times); no definite pattern was noted. However, it was observed on numerous occasions that surface water entered SJ from Sign Creek. The influx of large quantities of less saline water from Sign Creek may have been responsible for the lower surface salinity at SJ. Unfortunately, attempts to quantify input of fresher water from Sign Creek were unsuccessful due to the relatively high current velocity threshold of available current meters and a shortage of time and manpower. Bottom salinity at SJ during ebb tides usually decreased or remained unchanged.

Twelve complete flood cycles were monitored at SJ. The average length of flood tides was 6.2 hours (5-9 hours). All flood tides were directed toward North Inlet. Surface and bottom salinities usually decreased during the flooding period. Surface salinities generally remained lower than bottom salinities (9 times) throughout the flood tide. On three occasions, surface salinity was not substantially different from bottom salinity. Hydrographical data obtained from SJ substantiate the claim that a permanent nodal point, which limits exchange between North Inlet and Winyah Bay, exists in upper Jones Creek (Schwing and Kjerfve, 1980).

Average air and surface water temperatures during the year (Fig. 1-2 and 1-3) followed a similar pattern for NMF and SJ: decreasing from summer maxima from July through September to minima in January, then steadily increasing from February through June. Highest average surface water temperatures were recorded in July at NMF (31.46^{o}C) and SJ (32.95^{o}C). Lowest average surface water temperatures were recorded in January at NMF (3.75^{o}C) and SJ (3.80^{o}C). The highest average air temperatures were observed in August at NMF (28.90^{o}C) and September at SJ (29.81^{o}C). Lowest average air temperatures were recorded in January at NMF (8.50^{o}C) and SJ (7.42^{o}C). A more complete analysis of the physical and chemical characteristics of the creeks appears in Chapter 3.

Winyah Bay (Fig. 1-4) is a class B type estuary according to Pritchard's (1955) classification. The estuary has a mean depth of 4.2 m and a mean tidal amplitude of 1.0 m (1.2 m spring tides). Some of the freshwater input emanates from a 16,340 square mile watershed which drain swamps and marshes in northeastern South Carolina and southeastern North Carolina. This drainage arrives at the headwaters of Winyah Bay through the Great Pee Dee and Little Pee Dee Rivers which merge with the Waccamaw River just north of the city of Georgetown. The Black River drains another major watershed. The Sampit River drains a relatively small area of approximately 240 sq. miles (The Conservation Foundation, 1980).

Winyah Bay's widest dimension is in the center of the estuary (4.5 miles) and narrowest at the ocean entrance (0.75 miles). The width is

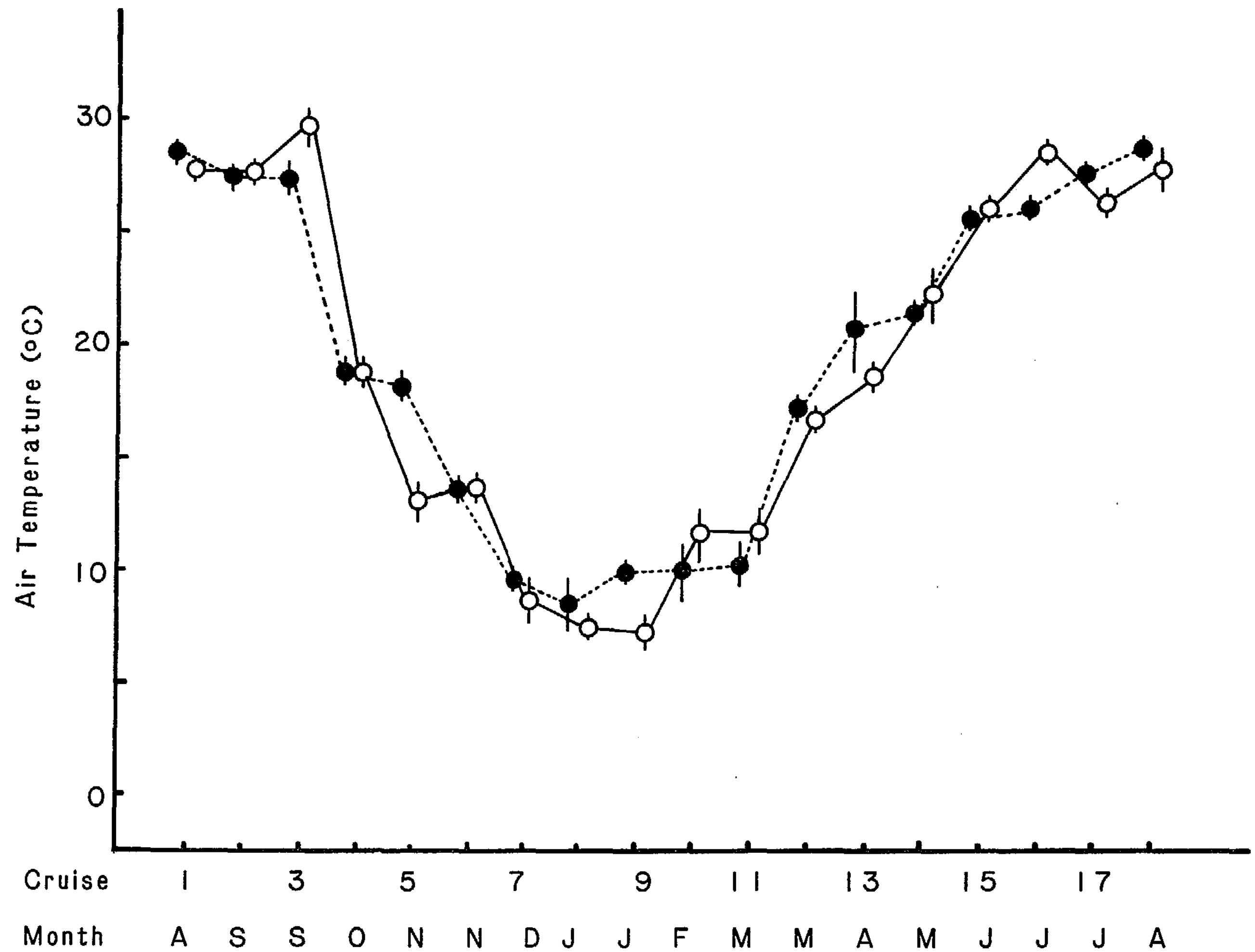


Figure 1-2. Mean air temperature for all cruises at NMF (dark circle) and SJ (open circle) Creeks. Vertical lines through the circles represent plus or minus the standard error.

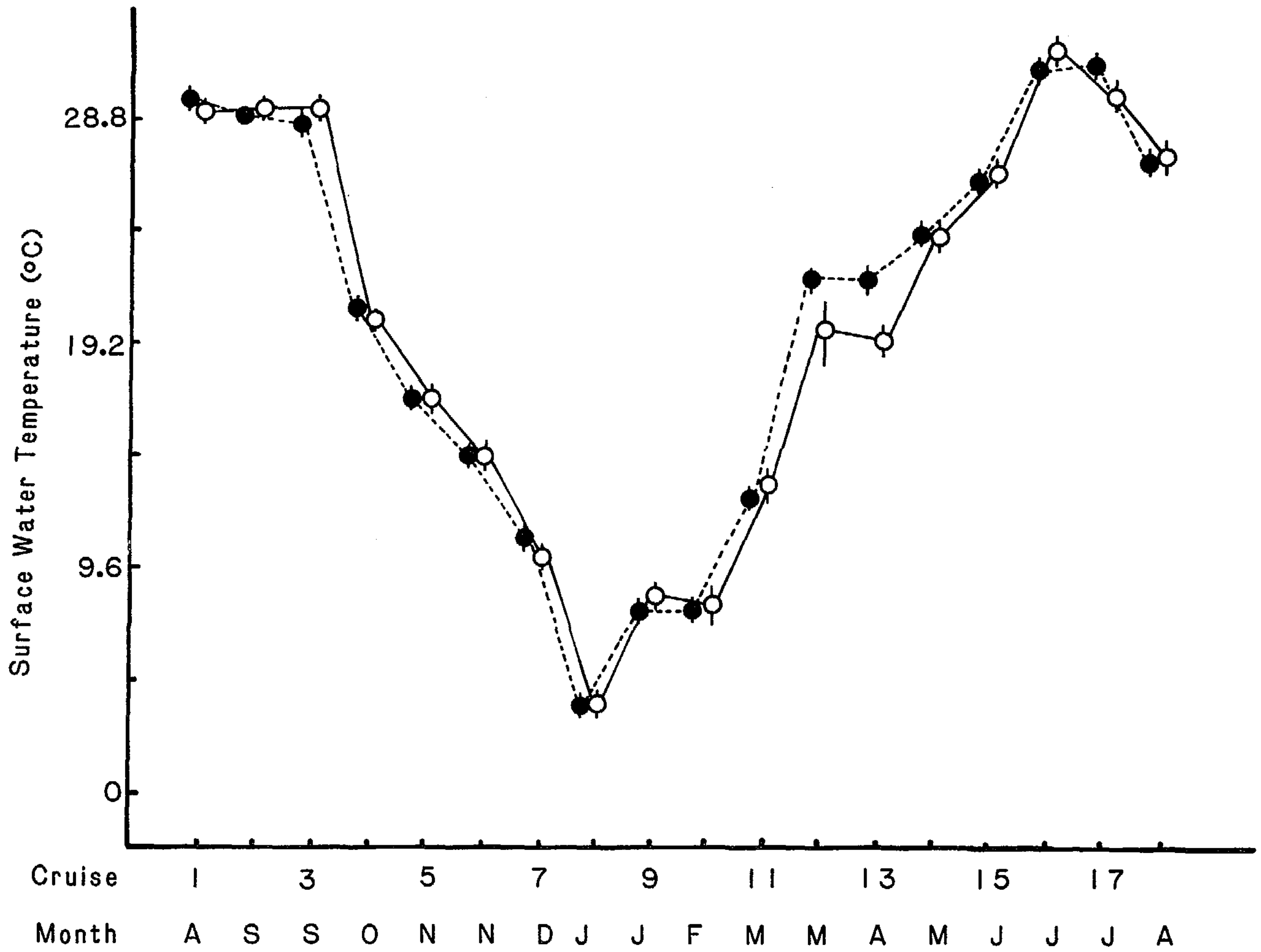


Figure 1-3. Mean surface water temperature for all cruises at NMF (dark circle) and SJ (open circle) Creeks. Vertical lines through the circles represent plus or minus the standard error.

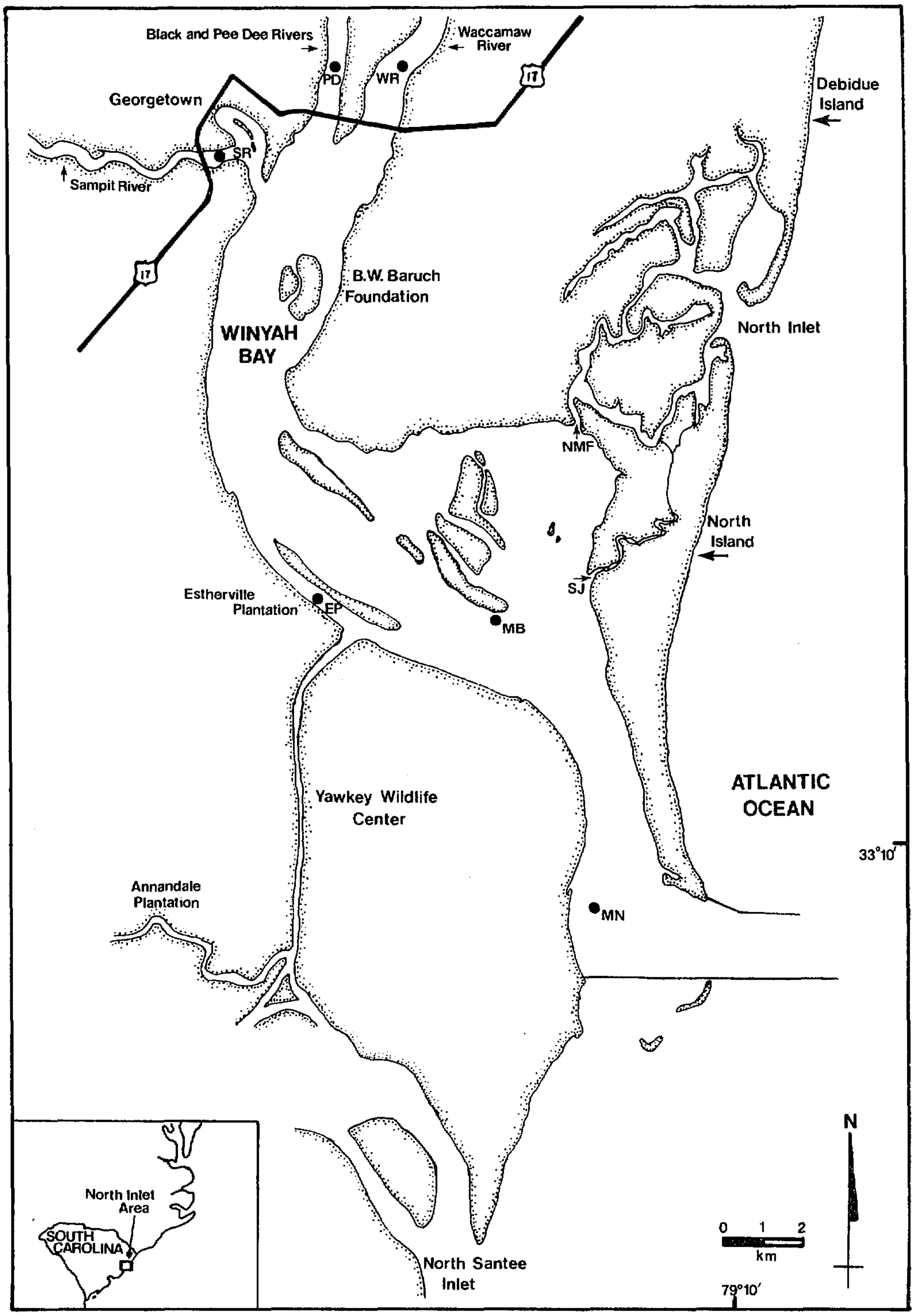


Figure 1-4. Map of Winyah Bay Estuary showing sampling locations at: Sampit River (SR), Pee Dee River (PD), Waccamaw River (WR), Esterville Plantation (EP), Mud Bay (MB), South Jones Creek (SJ), No Man's Friend Creek (NMF), and Mother Norton Shoal (MN).

about 1.3 miles in the upper bay where the rivers converge with the basin. Clay-rich sediments dominate the bottom in the upper bay and sand-rich substrates characterize the area near the ocean (Colquhoun, 1973). Few studies have examined hydrographic properties of Winyah Bay (Johnson, 1972; Mathews and Shealy, 1978; Trawle and Boland, 1979).

Winyah Bay is almost completely surrounded by marshes. More than 12,740 hectares (31,823 acres) of coastal marshes are associated with the system; approximately 87% of these marshes are influenced by the tides. Salt marshes (*S. alterniflora*) are confined to the lower bay. Brackish marshes (*S. cynosuroides*) comprise about 18% of Winyah Bay's wetlands (Tiner, 1977).

Water quality in Winyah Bay is primarily influenced by inputs from the Georgetown area. Georgetown is one of the most extensively developed areas of the Sea Island Coastal Region (Mathews et al., 1980). Winyah Bay has been classified as "SC" (lowest water quality classification), meaning that its waters are suitable for crabbing, commercial fishing and for the survival and propagation of marine flora and fauna (South Carolina Department of Health and Environmental Control, 1977; and South Carolina Pollution Control Authority, 1972). Shellfishing in Winyah Bay has been restricted since 1964 (U.S. Department of Commerce, 1979).

The Sampit River is the most heavily polluted river in the Winyah Bay system, receiving discharges from, among other sources, waste treatment plants, a pulp mill, and a steel mill. The Sampit River has high levels or organic pollutants and is ranked "SC", the lowest quality category used by the state (South Carolina Department of Health and Environmental Control, 1977; South Carolina Pollution Control Authority, 1972). Shellfishing has been prohibited in the Sampit River since 1964 (U.S. Department of Commerce, 1979). Pollution of the Pee Dee, Waccamaw and Black Rivers is dominated by agricultural runoff (Mathews et al., 1980).

Precise locations and characteristics (water quality, salinity range, and geomorphology) of the six sampling sites in Winyah Bay are summarized in Table 1-1. The Sampit River sampling site was located near the South Carolina State Ports Authority Terminal. Sampit River is a coastal river, originating in the coastal plain, and flow dominated by tidal actions (Mathews et al., 1980). The Sampit River was the smallest river sampled and exhibited the highest salinity regime.

The Pee Dee and Waccamaw Rivers supply most of the freshwater input to Winyah Bay. The area sampled in the Pee Dee River was approximately 1.25 km north of the bridge, located near mid-channel, and characterized by shallow depths and slow water velocities. Zooplankton and epibenthic sled samples from the Pee Dee River contained the heaviest detrital loads of any Winyah Bay sampling sites. The lowest range in salinities was obtained from the Pee Dee River. The Waccamaw River station was located mid channel approximately 1.25 Km north of Highway 17 bridge. The Waccamaw River was the widest and deepest river sampled. Salinities were the lowest recorded and water quality classification was highest.

The Esterville Plantation site was located near the middle of the Western Channel approximately 1 km north of the Intracoastal Waterway. Esterville Plantation had the greatest range in salinity and heavy detritus concentrations were common.

The Mud Bay location was near the lower end of Mud Bay, midway be-

Table 1-1. Locations, geomorphological characteristics, and water quality classification of the Winyah Bay sampling sites.

Station	Location (Lat.-Long.)	Approx. depth(m) at MLW	(a.) Sediment characteristics	(b.) Salinity range(o/oo)	(c.) Water quality classification
Sampit River	33°21'28"N 79°17'10"W	7.0	Soft mud	2.2-17.3	SC
Pee Dee River	33°22'29"N 79°15'40"W	3.0	Firm mud	2.9-10.5	B
Waccamaw River	33°22'30"N 79°14'45"W	8.0	Firm mud	0.0-7.8	A
Esterville Plantation	33°16'7"N 79°16'17"W	5.4	Sandy mud	10.3-30.6	SC
Mud Bay	33°15'28"N 79°13'10"W	3.9	Muddy sand and shell	11.9-31.7	SC
Mother Norton	33°12'6"N 79°11'17"W	3.6	Sand and shell	27.2-35.2	SC

(a.) Data obtained from benthic dredge samples
(b.) Data summarized from Chapter 10
(c.) Classification scheme:

A - suitable for direct water contact use
B - suitable for domestic supply after conventional treatment, suitable also for fish propagation, industrial and agricultural uses requiring water of lesser quality
SC - suitable for crabbing, commercial fishing, and for the survival and propagation of marine fauna and flora (lowest water quality classification)

(Adapted from South Carolina Department of Health and Environmental Control (1977) and South Carolina Pollution Control Authority (1972) as summarized by the Conservation Foundation (1980).

tween the main shipping channel and the spoil islands. The Mother Norton sampling site was located approximately 400 m from Mother Norton Shoal and was characterized by high current velocities, bottom sediments of sand and shell, and a narrow high range of salinities.

Other characteristics of the Winyah Bay sampling sites are discussed in Chapter 9.

CHAPTER 2. METHODS AND MATERIALS

The primary sampling program for NMF and SJ Creeks consisted of a series of nine cruises which were conducted approximately every six weeks from August 1980 through July 1981. On the third week between the six week cruises, another set of samples was collected to provide a more complete record of physical, chemical, and biological characteristics of the creeks. A schedule of cruise numbers and dates for the "major" intensive six week and alternate "mini" cruises at NMF and SJ is listed in Table 2-1. Cruise numbers and dates for the Winyah Bay collections which were done during the major sample weeks are also listed.

The major cruises began early on Monday mornings when a minimum of six persons transported equipment to the remote sampling station at NMF. Sampling commenced at 10 AM according to the outline in Table 2-2 and continued until the last collections were made at 10 AM on Tuesday. Three persons were usually on each of two shifts. On Wednesday morning the field team moved all equipment to SJ creek where the identical sampling schedule was carried out. On Friday of the same week, the field personnel collected samples at six stations from lower Winyah Bay to the river.

During the major samples, physical measurements were taken every hour. Water depth, vertical visibility (secchi disk), and current direction were recorded. Water temperature and salinity were measured at 30 cm below the surface and 30 cm above the bottom with an induction salinometer

Table 2-1. Cruise numbers and dates for all field collections made in NMF, SJ, and Winyah Bay. Odd numbered cruises are 24-hour major samplings at the creeks and 8-hour samplings in Winyah Bay. Even numbered cruises are mini samplings in the creeks.

CRUISE NO.	DATES	LOCATIONS NMF	SJ	WB
1	August 11-15, 1980	X	X	X
2	September 3	X	X	
3	September 22-26	X	X	X
4	October 13	X	X	
5	November 3-7	X	X	X
6	November 24	X	X	
7	December 15-19	X	X	X
8	January 6, 1981	X	X	
9	January 26-29	X	X	
	February 3			X
10	February 16	X	X	
11	March 9-12	X	X	
	March 6			X
12	March 31	X	X	
13	April 20-24	X	X	X
14	May 11	X	X	
15	June 1-5	X	X	X
16	June 22	X	X	
17	July 13-17	X	X	X
18	August 3	X	X	

Table 2-2. Generalized sampling program for major cruises at NMF and SJ Creeks. Period indicates the frequency at which each activity was conducted over the 24-hour cruise.

PERIOD	ACTIVITY
1 hr	Physical measurements of water column and air
2 hr	Water sample collection for nutrients and plant pigments
	Zooplankton net tows, 2 replicates
	Epibenthic sled tows, 3 replicates
3 hr	Gill net inspection
6 hr	Trawl collection

(Beckman RS5-3). Meteorological conditions including air temperature and wind speed and direction were also measured every hour. This same set of measurements was taken during the "mini" creek and Winyah Bay cruises.

Water samples were collected bi-hourly at the same depths as the temperature and salinity measurements. Bottom water samples were collected by means of a portable hand operated bilge pump with an intake hose which was suspended 30 cm from the bottom by a weighted metal frame. A 3 ml unfiltered sample was pipetted into pre-washed culture tubes. A second sample (15 ml) was filtered (Gelman glass fiber filter, Type -A/E, 25 mm) in the field, preserved with 2 drops of mercuric chloride, and stored in acid-washed scintillation vials. After field processing, the samples were frozen (dry ice), and returned to the laboratory for analysis.

In the laboratory, nutrient concentrations were determined on an Autotechnicon II Auto Analyzer. Filtered samples were used for the analysis of orthophosphate and (nitrate and nitrite) nitrogen. The basic method for analysis of orthophosphate followed that of Murphy and Riley (1962) as modified in Technicon Industrial Method No. 155-71W (1973) and described by Glibert and Loder (1977). The basic method for analysis of (nitrate and nitrite) nitrogen followed that of Technicon Industrial Method No. 158-71W (1972) as described by Glibert and Loder (1977). Unfiltered samples were used for the determination of total nitrogen and total phosphorous. Analysis was performed on an Autotechnicon II Auto Analyzer and followed the basic procedure suggested by D'Elia et al., (1977) as modified by Edwards (unpublished).

Concentrations of chlorophyll *a* and phaeo-pigments were also determined from the bottom and surface water samples. From the half liter samples, 20 ml was pipetted to a filtration apparatus consisting of Gelman glass fiber filters (type, -A/E, 25 mm). The filters were placed in scintillation vials that were prewashed in 90% acetone. Saturated magnesium carbonate solution (1 ml) was added and the vials were frozen in the field.

In the laboratory, 9 ml of 100% acetone were added to the frozen samples resulting in a 90% acetone extraction solution. The samples were periodically agitated and stored at $5^{o}C$ for 24 hours. A Turner fluorometer was used to determine chlorophyll *a* and phaeo-pigments according to the method of Yentsch and Menzel (1963). Further information on the procedure is found in Holm-Hansen et al. (1965) and Strickland and Parsons (1972).

Four types of gear were used to sample various animal communities at NMF and SJ Creeks. Microscopic plankton were collected with a zooplankton net and somewhat larger swimming organisms which live near the bottom were collected with an epibenthic sled. Large bottom (benthic) invertebrates and fishes were collected with an otter trawl and larger subsurface fishes were caught in gill nets.

Zooplankton collections were made every two hours with a 30 cm diameter net constructed of 153μ mesh nytex (Fig. 2-1). A torpedo-type flowmeter was mounted inside the mouth of the net to estimate the volume of water filtered by the net as it was towed from a small boat. The weighted net was lowered to the bottom, then towed against the current for 90 seconds. During the tow, the boat speed was increased to allow

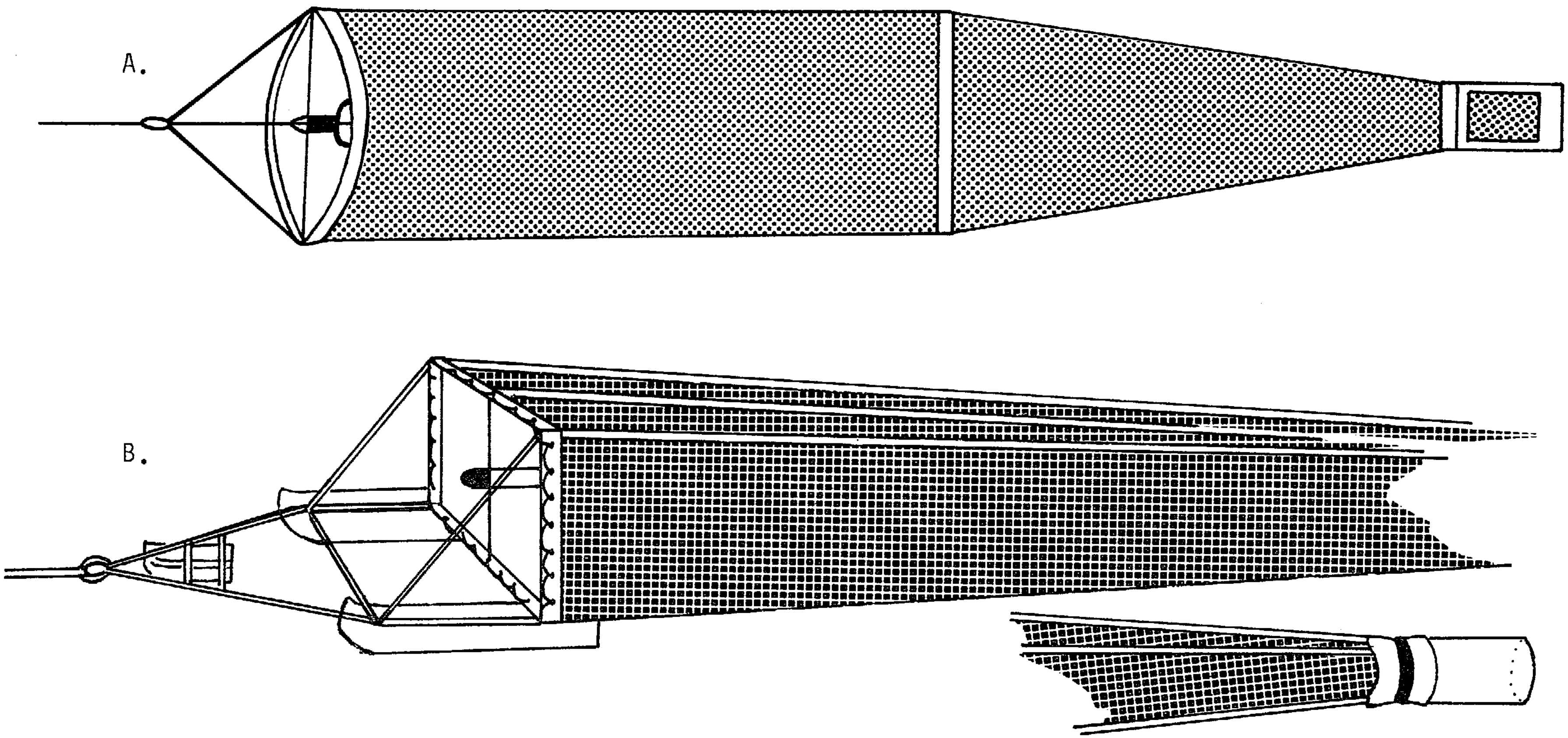


Figure 2-1. Generalized designs for nets used to collect microscopic animals.
A. zooplankton net B. epibenthic sled

the net to sample the entire water column from bottom to surface. The sample was removed from the codend of the net and preserved in a 10% borax buffered formalin solution with rose bengal. A second tow immediately followed the first.

In addition to the bi-hourly collection during the 24-hour major cruises at each creek, zooplankton collections were taken at high and low tides at both creeks on the "mini" cruises. The same equipment and procedure were used at the Winyah Bay stations.

In the laboratory a 2 ml subsample was removed from a well-mixed sample. Copepod crustaceans, which dominated the samples, were counted and identified to species. All other organisms were identified to designated taxonomic categories and counted. Preliminary tests showed no significant differences between subsample counts, so only one subsample was counted. The processed 2 ml aliquot was remixed with the original sample and stored in 10% buffered formalin.

Small motile organisms which live on or just above the bottom were collected with an epibenthic sled (Fig. 2-1). The apparatus consists of a rectangular steel frame (51 x 30 cm) which orients the mouth of a 365μ mesh nytex plankton net perpendicular to the bottom. This frame is mounted on a horizontal frame which slides over the bottom on three skis. The sled was pulled behind a small boat in the direction that the tidal currents were moving. A marked towpath was followed in each four minute tow. The volume of water filtered was estimated with a flowmeter mounted inside of the net mouth. Three consecutive tows (replicates) were made every two hours. The samples were preserved in a 10% borax buffered formalin solution with rose bengal.

The same procedure was followed on the "mini" and Winyah Bay cruises. Zooplankton and sled collections were made simultaneously so that the results could be compared.

In the laboratory, entire samples were processed unless a large volume of detrital material occurred, in which case the sample was split. All organisms were identified to the lowest possible taxon and counted. Mysid shrimp and fish larvae were identified to species, counted, and measured. The processed portion of the collection was remixed and the original sample was stored in 10% buffered formalin.

Fish and macroinvertebrate collections were made during the major cruises at both creeks with a 480 cm (16 ft.) headrope otter (shrimp) trawl (Fig. 2-2). The body of the net is 38 mm (1½ in.) stretch mesh nylon and the cod bag is 32 mm (1¼ in.) stretch mesh nylon. The doors are 61 x 30 cm (24 x 12 in.). A single tow was made along a marked towpath every six hours. The net was pulled against tidal currents at the speed of about three knots.

All organisms in the collections were identified to species. Large specimens were measured and weighed in the field, but most crabs, shrimps, squids, and fishes were returned to the laboratory. Blue crab width was measured from point to point to the nearest millimeter. Penaeid shrimp length was measured from the tip of the rostrum to the end of the carapace ($\pm$1mm). Fish length was measured from the anterior extremity to the end of the caudal fin (tail). Up to 100 of each species of invertebrates and fishes were measured in each collection. Total number and

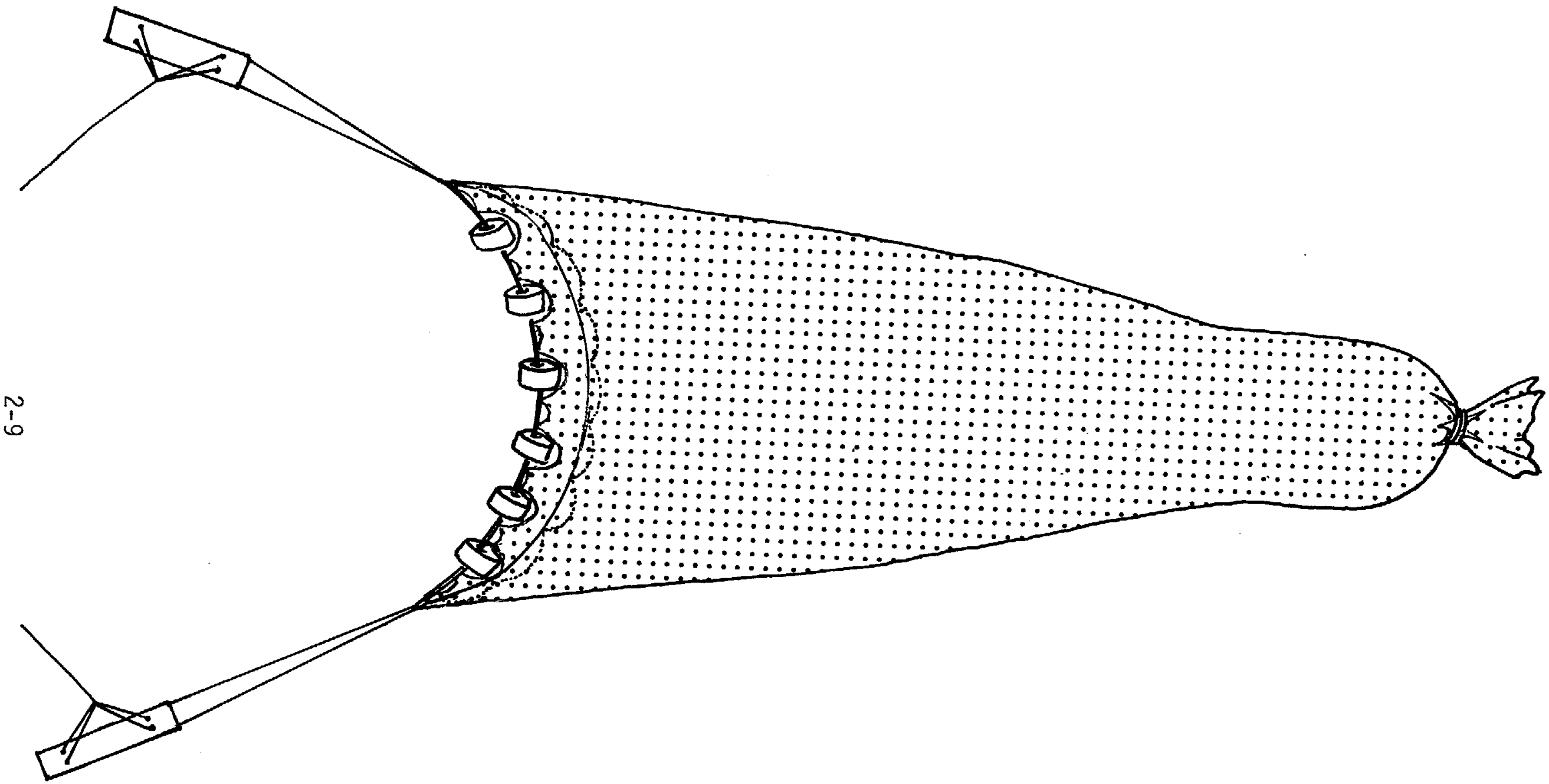


Figure 2-2. Generalized form of semi-balloon otter trawl used to collect macroinvertebrates and fishes.

weight were determined for each species in each collection. Gut content analyses were conducted on all large fishes and representative subsamples of smaller ones. Information on the reproductive condition of many species was collected.

Gill nets were set at the beginning of each major cruise and inspected every three hours. Large quantities of detritus or strong tidal currents which fouled the nets restricted the use of this gear during several cruises. Three 15 m (50 ft.) panels, one each of 7.6, 19.0, and 30.5 cm (3,7.5, and 12 in.) stretch monofilament webbing were set perpendicular to the creek axis. Fishes and crabs were identified, counted, and measured in the field.

CHAPTER 3. PHYSICAL MEASUREMENTS AND WATER CHEMISTRY

Air temperature and surface and bottom water temperatures at both No Man's Friend (NMF) and South Jones (SJ) Creeks were highest from June through September (greater than $25^{o}C$) and lowest in January and February (less than $12^{o}C$) (Fig. 3-1 and 3-2). Maximum surface and bottom water temperatures at both creeks were recorded in June and July (approximately $30^{o}C$). Minimum water temperature values near $4^{o}C$ occurred in January. Air and water temperatures typically increased from January to June and decreased from September to January.

Water temperature is primarily influenced by solar radiation. The temperature of riverine inputs and tidal flow from the sea also affect the temperature regime at NMF and SJ. Shallow basins such as Mud Bay are particularly susceptible to temperature variations due to atmospheric conditions. Wind can alter water temperature by removing heat from the water through increasing evaporation. High wind velocities may also cause the breakdown and prevent further formation of a thermocline (temperature stratification within the water column). Winds and high current velocities also create highly turbid conditions which may affect water temperature. Relatively large diel, diurnal, and seasonal water temperature fluctuations were observed at NMF and SJ.

The flooding of marsh surface and mudflats during high tides directly

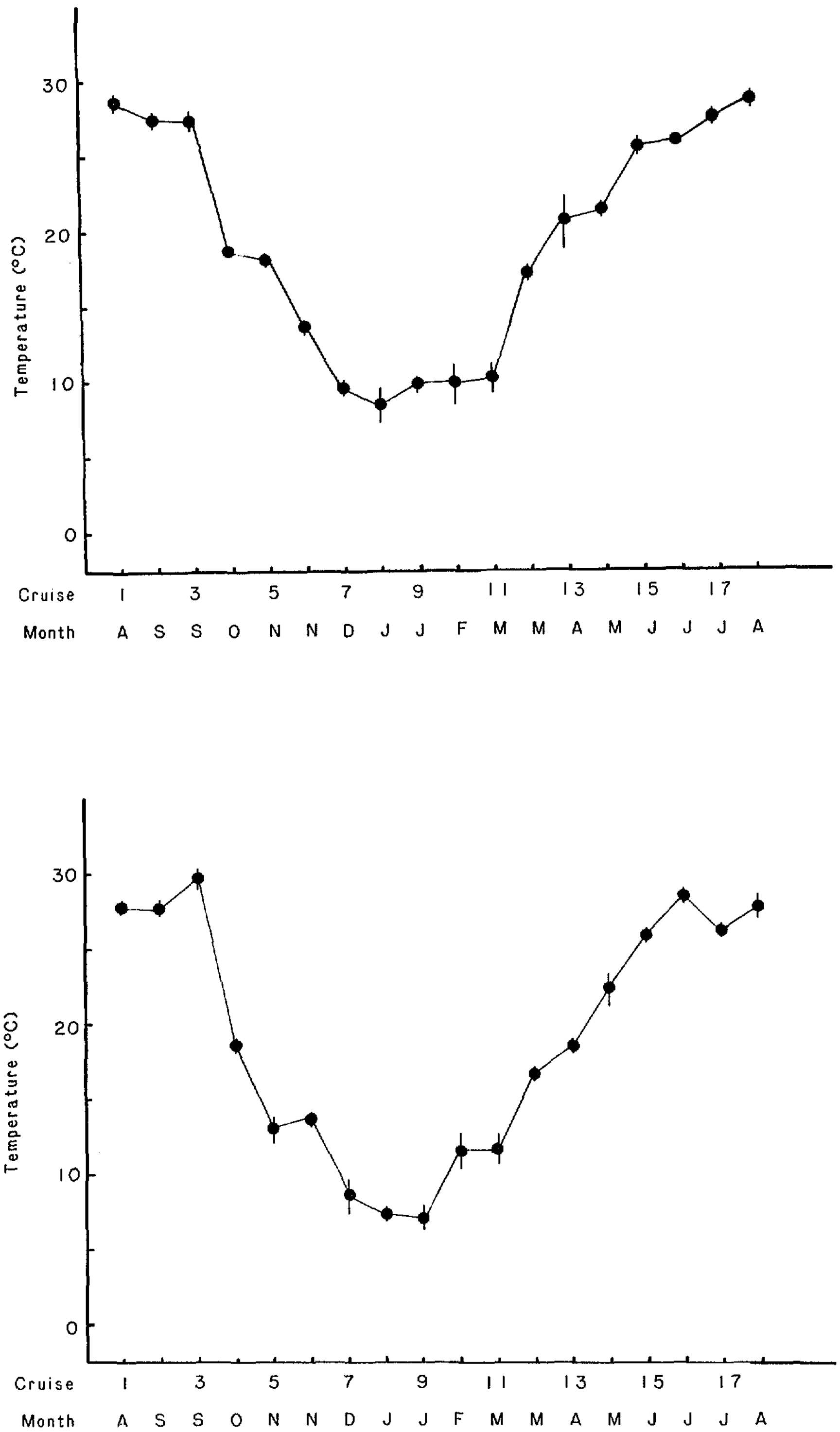


Figure 3-1. Mean air temperatures for all cruises at NMF (above) and SJ (below) Creeks. Vertical lines through the circles represent plus or minus the standard error.

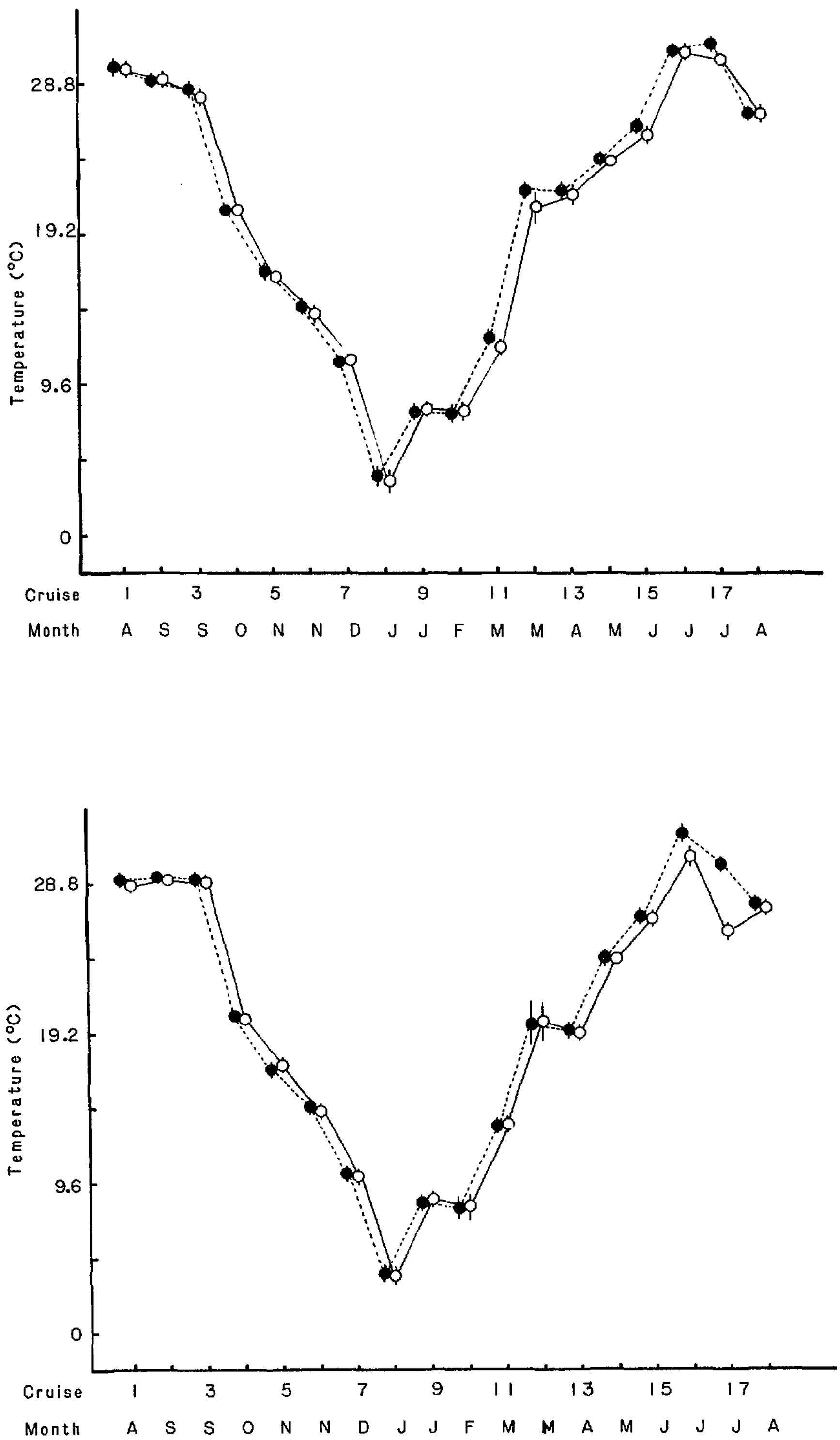


Figure 3-2. Mean surface (above) and bottom (below) water temperatures at NMF (dark circle) and SJ (open circle) Creeks. Vertical lines through the circles represent plus or minus the standard error.

affects the water temperature. During the summer, exposed marsh may become much warmer than the surrounding waterways, and water ebbing from the intertidal zone after flood conditions can elevate water column temperature. Conversely, exposed intertidal areas may be much cooler than flooding waters during the winter resulting in increased temperatures of the intertidal sediments and decreased water temperatures.

Salinity is also an important factor in determining water temperatures. Fresh water has a higher specific heat than does salt water. This means that more heat is required to warm a given amount of fresh water than the same amount of salt water. Precipitation effects on water temperatures are manifest in salinity changes.

Salinity has been defined as "the total amount of solid material, in grams, contained in one kilogram of sea water when all the carbonate has been converted to oxide, the bromide and iodine replaced by chlorine, and all organic matter completely oxidized" (Cushing and Walsh, 1976). Ions present in seawater and their percentage composition include sodium (30.4), potassium (1.1), calcium (1.16), magnesium (3.7), chlorine (55.2), sulfate (7.7), and carbonate (0.35). These ions plus strontium, bromide, and boric acid constitute more than 99% of the total salts in seawater (Reid and Wood, 1976). The salinity of oceanic waters averages 35 parts per thousand (o/oo), whereas freshwater is considerably less than 1 o/oo. The proportion of dissolved salts in estuarine waters generally resembles that of salt water, although the total concentration changes along the length of the estuary (Reid and Wood, 1976).

Maximum values for surface salinity were recorded in February at

NMF (35.0 o/oo) and January at SJ (31.9 o/oo) (Fig. 3-3). Bottom salinity was highest in January at NMF (36.0 o/oo) and June for SJ (34.4 o/oo). Lowest surface and bottom salinities for both creeks were recorded in March. Cruise to cruise variations in surface and bottom salinities did not follow a regular pattern. Salinities for NMF and SJ primarily result from the dilution of sea water by the freshwater river input. The degree of dilution is dependent on the amount of freshwater entering the estuary as well as tidal intrusion of sea water. Amount of sea water entering the estuary is related to lunar phase (i.e. spring and neap tides), wind, and meteorological conditions.

Average surface and bottom salinities were generally lower at SJ than at NMF reflecting the greater contribution of high salinity North Inlet water to NMF (refer to Chapter 1). Salinities varied considerably over the sample period and variations on the order of 15-20 o/oo were common. Maximum salinities were generally recorded near the slack flood tide and minimum values near slack ebb tide. Large differences between surface and bottom salinities throughout many of the tidal stages observed were related to the formation and maintenance of a halocline (light freshwater flowing over denser brackish water). Haloclines were only observed to occur during periods of low turbulent mixing when wind and current velocities were low. For example, the halocline observed in NMF in January, where surface salinities averaged 11.5 o/oo less than bottom salinities, occurred during a period when tidal amplitude (1.2 m) and current velocity were low, and wind speeds were usually less than 5 mph. Over half of the hourly observations were characterized by wind speeds of less than 2 mph. A 17 o/oo salinity difference between surface

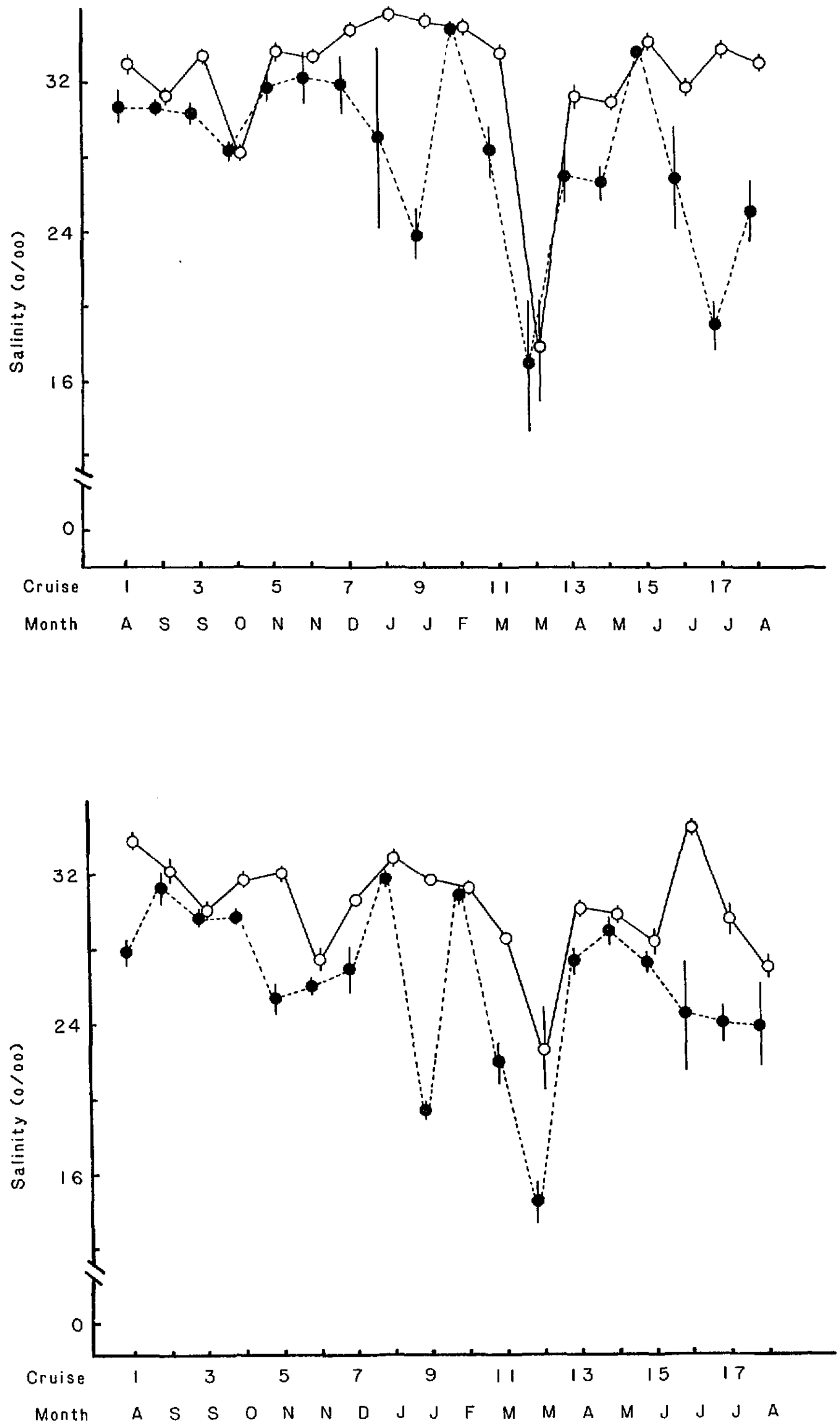


Figure 3-3. Mean surface (above) and bottom (below) salinities at NMF (dark circle) and SJ (open circle) Creeks. Vertical lines through the circles represent plus or minus the standard error.

and bottom waters was observed during the last four hours of the ebb tide. The stratification and mixing of water masses of different salinity and chemical content probably affects the distribution of many organisms in the two creeks and the maintenance of a permanent community structure.

Vertical visibility was measured with a Secchi disk during every cruise. Secchi disk transparency is directly related to the vertical coefficient of light absorbtion which delineates the region from the surface to the depth at which 99% of the surface light has disappeared (Cole, 1975). This region is referred to as the euphotic zone, and is ecologically important because little or no photosynthesis can occur below this zone.

Secchi disk visibility in estuarine areas is primarily affected by turbidity, which is defined as the concentration of particulate matter suspended in the water column. The major component responsible for estuarine turbidity is silt and its concentration is dependent on rainfall, currents, wind, agricultural runoff, and erosion within the creeks. High densities of plankton and detrital material also affect light penetration serving to effectively reduce the depth of the euphotic zone.

Average secchi disk visibility at NMF and SJ was lowest in June (0.32-0.35 m) and highest in January and February (1.2-1.84 m). Secchi disk visibility at NMF was approximately 0.5 m or less for the period August through October, 1980, and increased steadily to a maximum of 1.84 m in January, 1981 (Fig. 3-4), then declined sharply to approximately 0.5 m in March, 1981. Secchi disk visibility at SJ followed a similar pattern with the maximum value of 1.65 m occurring in February, 1981. However,

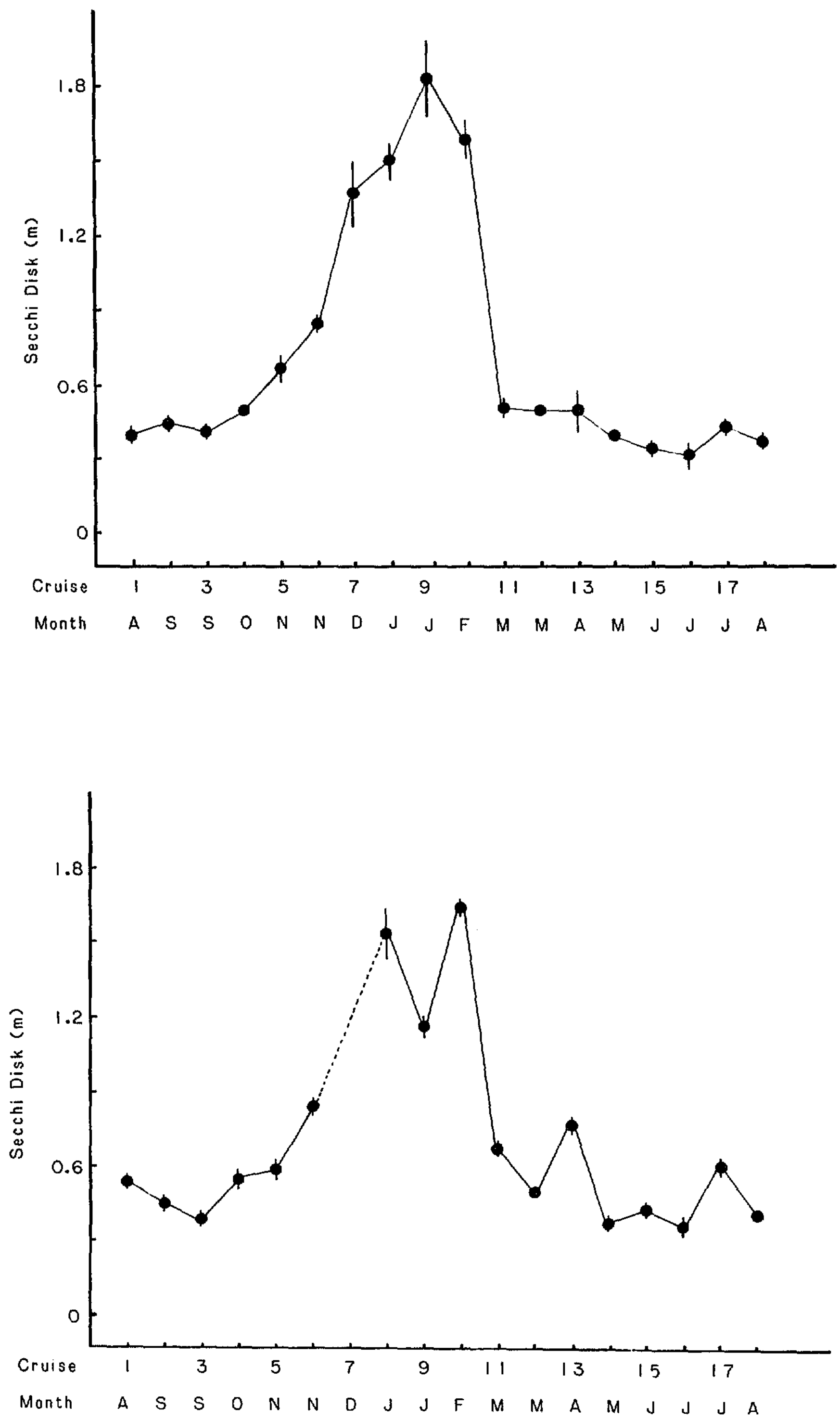


Figure 3-4. Mean secchi disk visibilities at NMF (above) and SJ (below) Creeks. Vertical lines through the circles represent plus or minus the standard error.

secchi disk visibility in SJ showed a pronounced decline during the second January sampling date, which was not evident in the NMF data. Also, secchi disk readings at SJ fluctuated more during March through August, 1981, than did the corresponding NMF data.

Low secchi disk readings from March through October corresponded to the increased abundance of phytoplankton and detritus in the water column and most intense periods of agricultural activity in the upper estuary. High secchi disk visibility corresponded to periods of low productivity (refer to Chapter 4) and minimal agricultural runoff. Vertical visibility generally followed a similar pattern at NMF and SJ. Higher variability exhibited by the data in SJ during March through August probably resulted from a number of factors including current velocity, wind, and detrital concentrations. The large decrease in average secchi disk visibility in late January was apparently the result of a localized phytoplankton bloom. Concentrations of both chlorophyll *a* and phaeo-pigments (refer to Fig. 4-1 and 4-2 in Chapter 4) in SJ were almost twice as large as those recorded in NMF.

Water sample analyses were conducted to determine the relative concentration of total nitrogen and its various forms in the two creeks. Nitrogen is essential in the synthesis of protein which is a major constituent of living cells and, therefore, is essential to the existence of an ecosystem. Atmospheric nitrogen acts as a reservoir for a complex cycle involving plants, animals, and various forms of the element. Nitrogenous compounds are made available to the estuarine environment by bacterial fixation of elemental nitrogen, precipitation, surface runoff, riverine inputs, photochemical and lightning fixation, decomposing plant and animal tissues, and animal excretory products (amino acids, urea, uric acid, ammonia). Available nitrogen is transformed into nitrates through bacterial action. Ammonium-nitrogen and, to a lesser extent, nitrite-nitrogen can be utilized by some phytoplankton species, although nitrate-nitrogen is primarily taken up by the cells and transformed into complex proteins (Russell-Hunter, 1970). Concentrations of inorganic nitrogen compounds (ammonia, nitrite, nitrate) regulate the productivity of an aquatic ecosystem because they are used in the synthesis of plant proteins which form the base of the aquatic food web.

Surface total nitrogen at NMF and SJ was highest in July (approximately 76 μg At.N/l) and lowest in December (26 and 32 μg At.N/l, respectively) (Fig. 3-5). Bottom total nitrogen was highest in June at NMF (83 μg At.N/l) and July at SJ (80 μg At.N/l). Lowest bottom total nitrogen values were recorded at NMF and SJ in December (21 and 25 μg At.N/l respectively). Total nitrogen in both creeks at surface and bottom generally exhibited a similar pattern (Fig. 3-5). Values decreased from August or September to a minimum in December and typically increased from December through June or July.

Nitrate-nitrite values at NMF and SJ appear to exhibit a bimodal pattern. Maximum values were recorded in November or December and March or April (Fig. 3-6). Surface nitrate-nitrite concentrations were highest in March and December at NMF (6.8 and 3.5 μg At.N/l) and March and November at SJ (8.2 and 6.3 μg At.N/l). Lowest values were recorded in July at NMF (less than 0.1 μg At.N/l) and August at SJ (0.5 μg At.N/l). Bottom nitrate-nitrite values were highest in November and April at NMF (1.7 and 1.5 μg At.N/l) and December and March at SJ (3.7 and 3.1 μg At.N/l). At

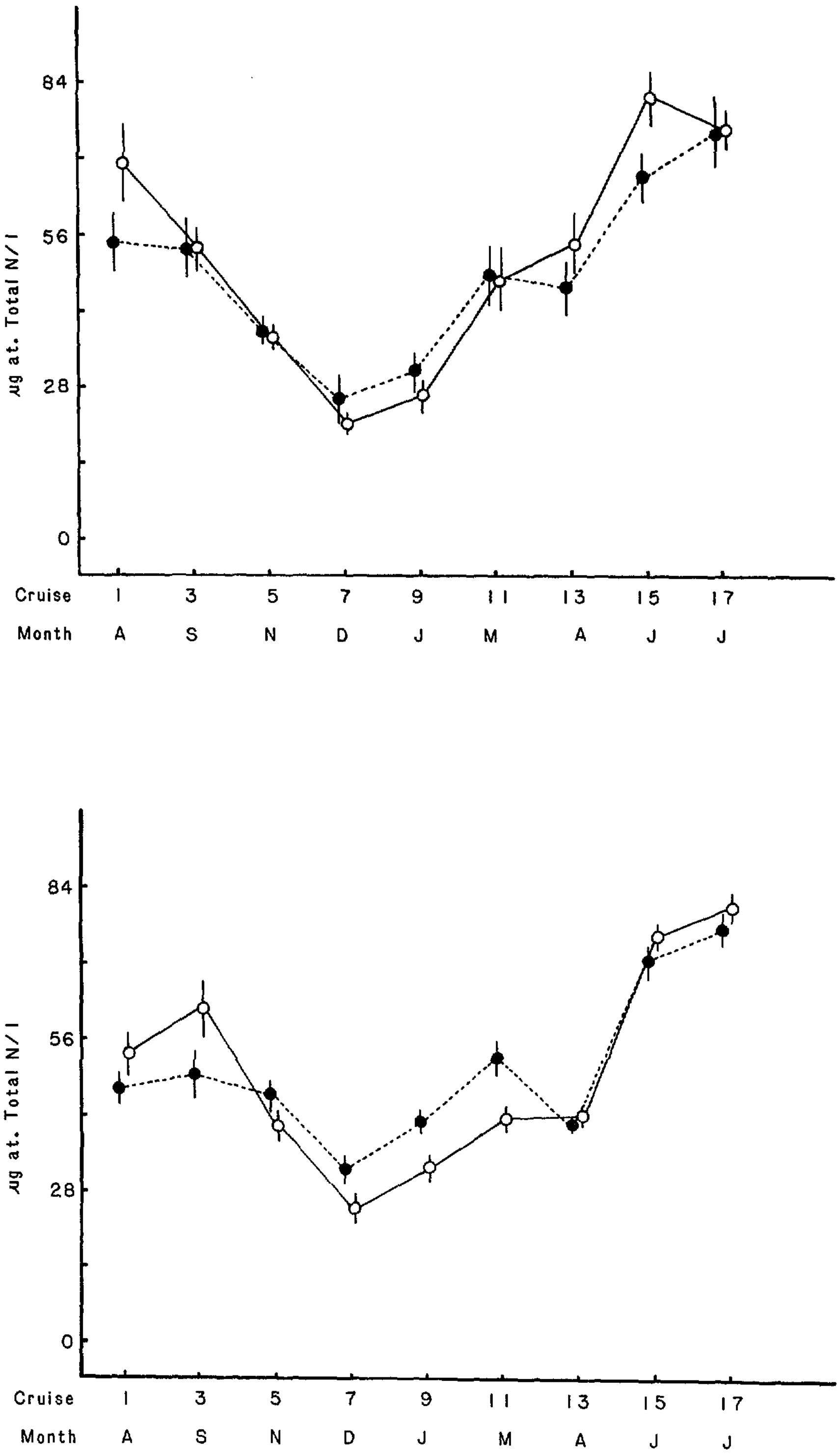


Figure 3-5. Mean surface (above) and bottom (below) concentrations of total nitrogen at NMF (dark circle) and SJ (open circle) Creeks. Vertical lines through the circles represent plus or minus the standard error.

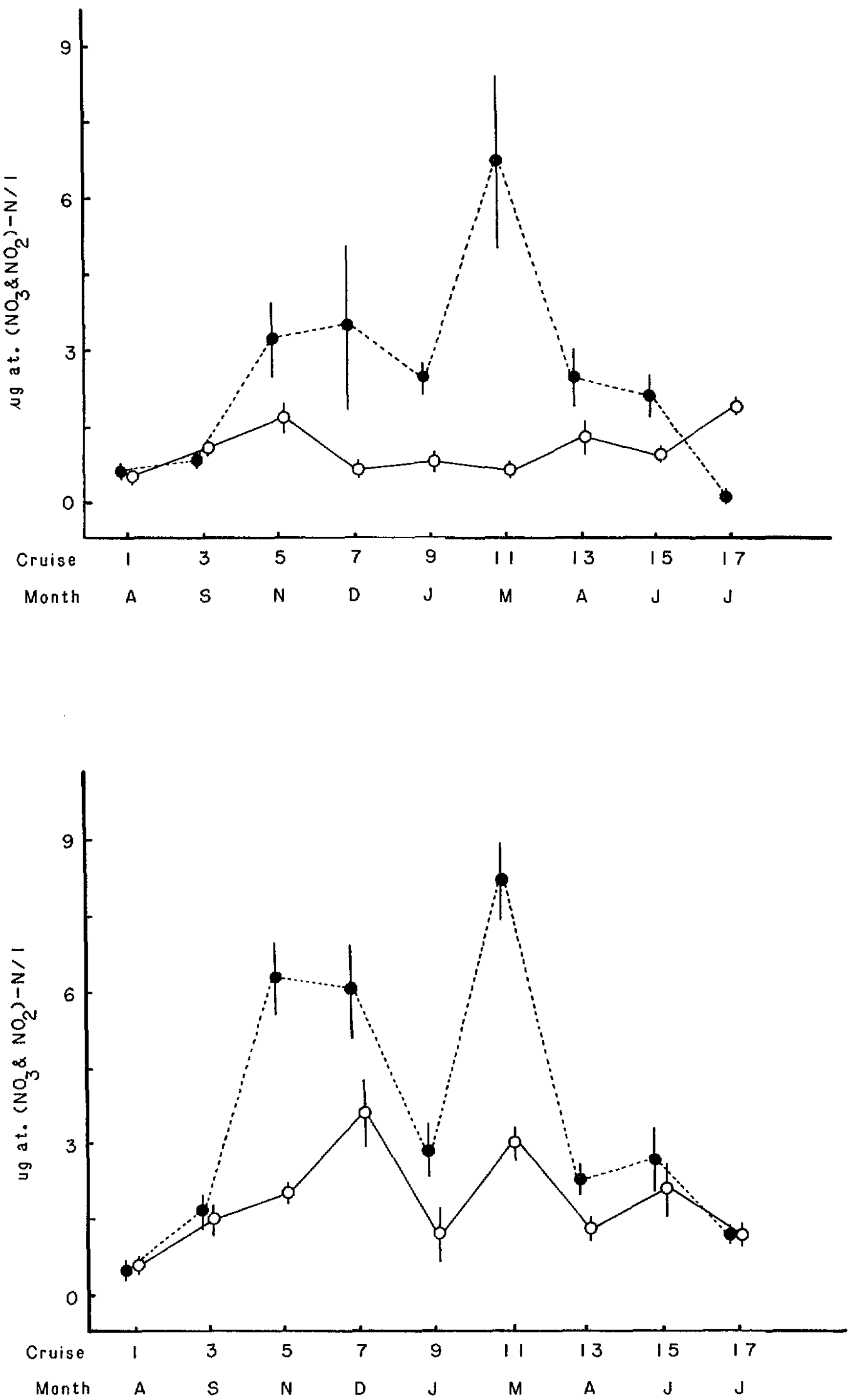


Figure 3-6. Mean surface (above) and bottom (below) concentrations of (nitrate and nitrite) nitrogen at NMF (dark circle) and SJ (open circle) Creeks. Vertical lines through the circles represent plus or minus the standard error.

both creeks, bottom nitrate-nitrite values were lowest in August (0.6 µg At.N/l).

High values for total nitrogen at both creeks from June through September correspond to periods of high productivity when concentrations of chlorophyll *a* and phaeo-pigments are greatest (Chapter 4). As phytoplankton productivity increases, simultaneous increases in animal biomass may be expected. During this period, metabolic activity increases and higher levels of animal excretion of nitrogen wastes and decomposition of plant and animal tissues occur, thereby increasing the concentrations of total nitrogen in the water column.

Low values for nitrate-nitrite at both creeks during June through September also correspond to periods of maximum concentrations of chlorophyll *a*. Nitrate-nitrogen and nitrite-nitrogen are easily assimilated by phytoplankton. During periods of peak abundance of phytoplankton, nitrate (N) and nitrite (N) are assimilated by the phytoplankton as fast as they become available. Conversely, high nitrate-nitrite values can be related to periods of low utilization by phytoplankton (low chlorophyll *a* values), and may represent a disproportionate share of the total nitrogen present in the water column during these times.

Seasonal data for nitrate-nitrogen reflect findings from other salt marsh and estuarine studies where higher concentrations were found to occur during winter months and lower concentrations during the summer (Norall and Mathieson, 1976; Mauriello and Winfield, 1978; Daly and Mathieson, 1981). Declines in nutrient concentrations have been related to phytoplankton productivity (Thayer, 1971) and phytoplankton density has been shown to have a significant inverse relationship to nitrate (Toner, 1981). In estuarine studies near Beaufort, NC, nitrogen availability has been suggested to be the most critical factor in determining rates of photosynthesis (Thayer, 1974).

Water samples collected on major cruises were also analysed for phosphorus. Phosphorus is vital in the operation of cellular energy transfer systems. Phosphorus is typically scarce in unpolluted environments and is often a major limiting factor to aquatic productivity. Concentration of phosphorus in estuarine waters is primarily affected by basin morphometry, geochemistry of the watershed, input of organic matter, organic metabolism in the water column, and the rate of loss of phosphorus to the sediments (Reid and Wood, 1976). In a natural salt marsh in Delaware, data indicated that total and inorganic phosphorus concentrations were directly related to salinity and concentrations of the three forms of phosphorus (total, organic, and inorganic) were directly related to tide stage, lunar phase, and day of year (Reimold and Daiber, 1970). Precipitation may also contribute significant quantities of nutrients to salt marsh and estuarine environments (Reimold and Daiber, 1970).

In estuaries a large pool of phosphorus is retained in the sediments (Rochford, 1951; Pomeroy et al., 1965 and 1969; Pomeroy, 1970). This pool of phosphorus is made available to the aquatic environment by ion exchanges between sediments and overlying water and by microorganisms (Gooch, 1968; Pomeroy et al., 1969). *Spartina alterniflora* may also play an active role in the circulation of phosphorus in the sediments to the marsh surface (Pomeroy et al., 1969).

Decomposition also serves to increase concentrations of phosphorus in the aquatic environment. Decomposition results in the direct release of nutrients from dead organic material to the environment. The importance of the *Spartina* detritus food chain in recirculation of nutrients has been demonstrated (Odum and de la Cruz,1967). Bacterial assimilation of detrital phosphorus and consequent grazing of detrital bacteria by zooplankton results in very rapid turnover times (approximately 2 minutes) of the free pool of phosphate (Barsdate et al., 1974).

Phosphorus, usually in the form of orthophosphate, is rapidly assimilated by phytoplankton as soon as it is made available and is then passed on to higher trophic levels through herbivory and subsequent predation. Uptake of orthophosphate in surface waters and in vertical profiles has been shown to be directly proportional to the standing stocks of phytoplankton and bacterioplankton (Krempin et al.,1981).

Surface total phosphorus concentration was highest in July at NMF (4.1 μg At.P/l) and June at SJ (2.8 μg At.P/l) (Fig. 3-7). Surface total phosphorus was lowest in January at both creeks (0.6 μg At.P/l). Bottom total phosphorus was highest in June at NMF (5.4 μg At.P/l) and September at SJ (4.4 μg At.P/l). Bottom total phosphorus was lowest in January at both NMF and SJ (0.2 and 0.4 μg At.P/l, respectively).

Seasonal values for orthophosphate-phosphorus apparently follow a bimodal pattern with peaks occurring in November or December and June or July. Concentrations of surface orthophosphate-phosphorus were highest in November at NMF (0.7 μg At.P/l) and December at SJ (0.6 μg At.P/l) and lowest in January at both creeks (0.2 μg At.P/l) (Fig. 3-8). Concentrations of bottom orthophosphate-phosphorus were highest in November at

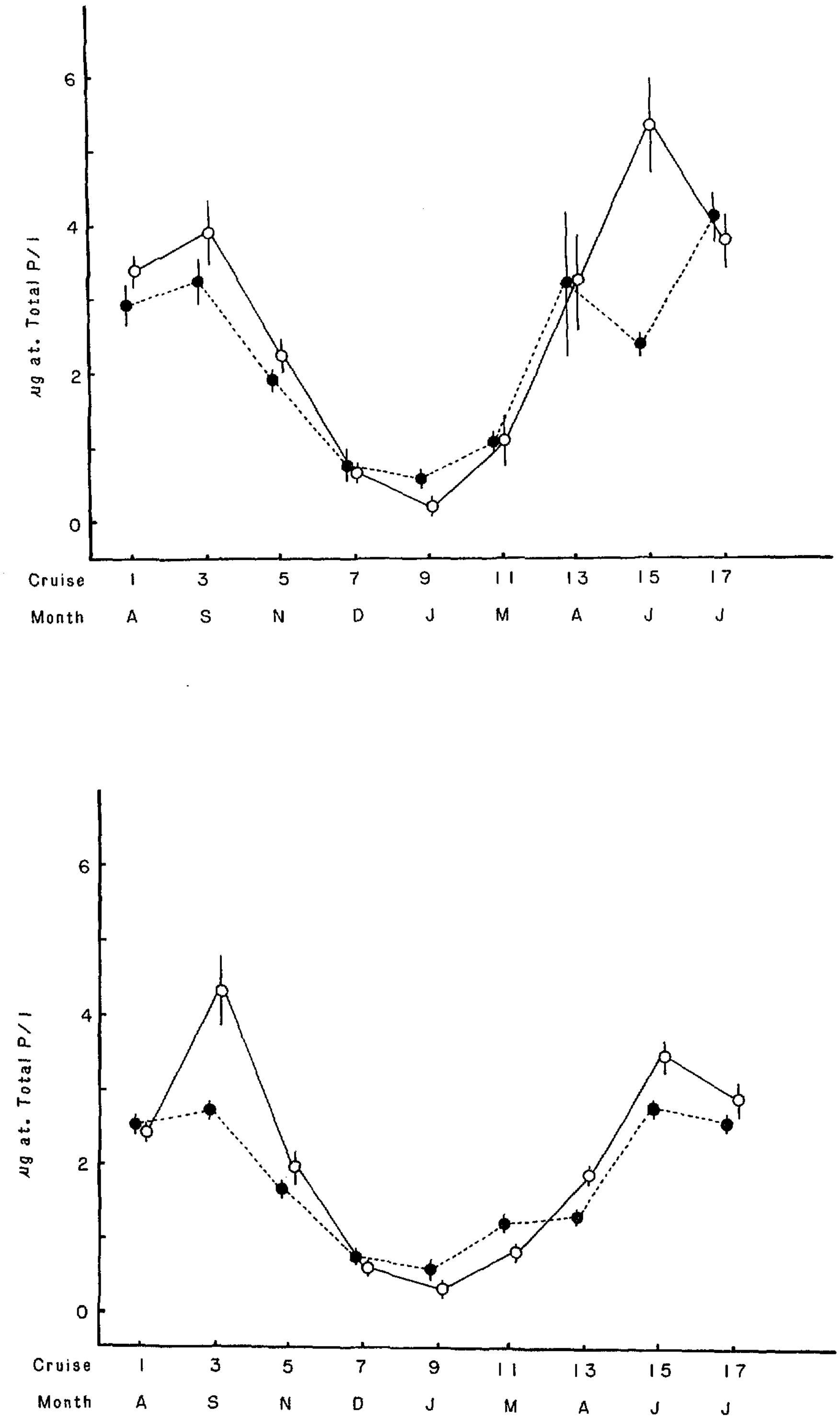
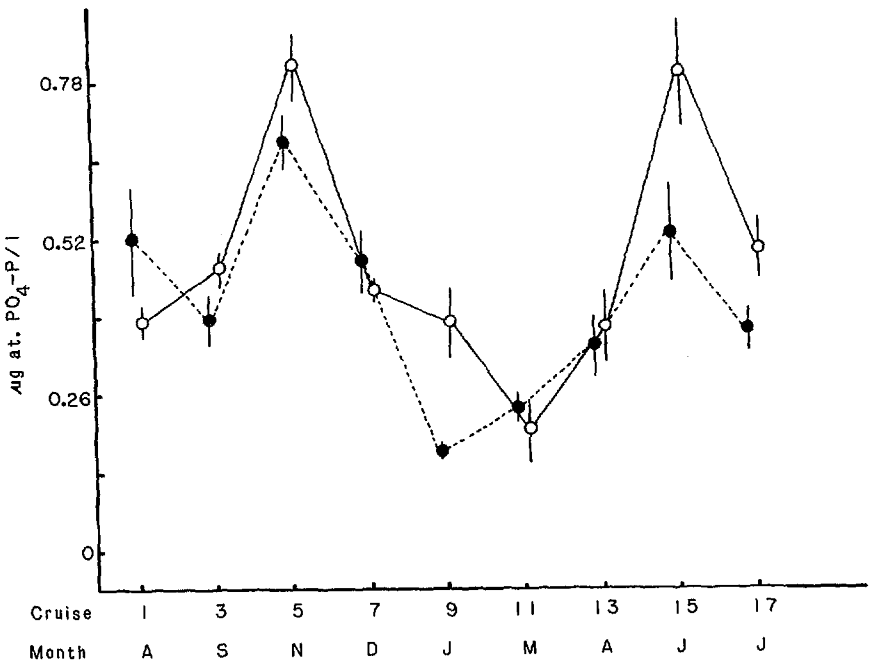


Figure 3-7. Mean surface (above) and bottom (below) concentrations of total phosphorus at NMF (dark circle) and SJ (open circle) Creeks. Vertical lines through the circles represent plus or minus the standard error.



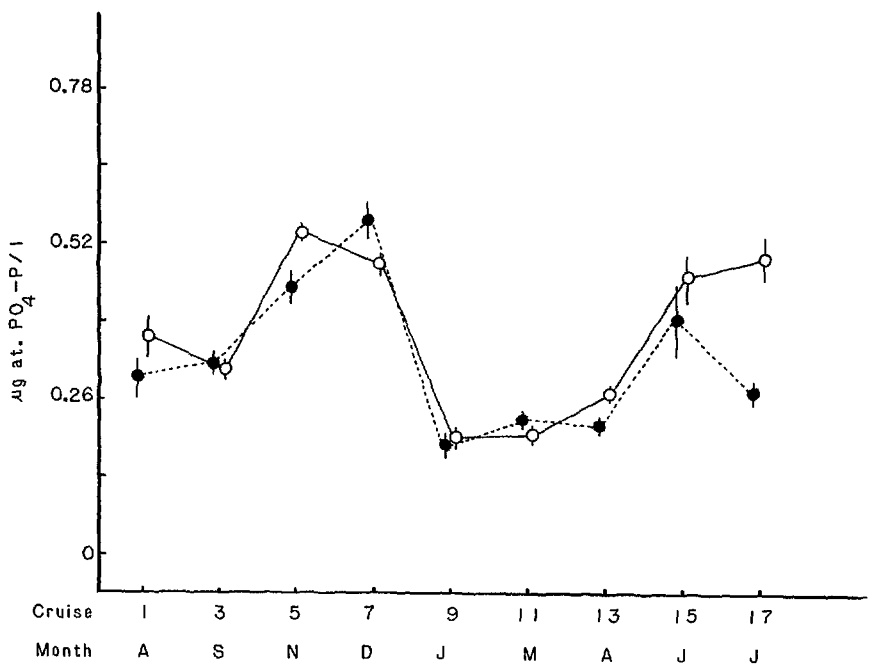


Figure 3-8. Mean surface (above) and bottom (below) concentrations of orthophosphate-phosphorous at NMF (dark circle) and SJ (open circle) Creeks. Vertical lines through the circles represent plus or minus the standard error.

NMF and SJ (0.8 and 0.5 μg At.P/l, respectively). Lowest values for bottom orthophosphate-phosphorus (0.2 μg At.P/l) were recorded in March at NMF and January at SJ.

High values for surface and bottom total phosphorus at both creeks during June through September may reflect the high concentration of phytoplankton and detritus in the water. Conversely, low surface and bottom values of total phosphorus in January in both creeks may reflect the low density of phytoplankton and detrital matter in the water. Seasonal patterns of phosphorus concentration closely resembled those of a Delaware salt marsh (Reimold and Daiber, 1970).

High surface and bottom orthophosphate values at NMF and SJ in November or December and June or July may indicate that orthophosphate is being made available to the environment faster than it can be utilized. Low values in January and March may be explained by the increase in phytoplankton biomass and utilization of the orthophosphate. Seasonal orthophosphate concentration patterns reflect similar findings from Flax Pond, a tidal marsh on Long Island (Woodwell and Whitney, 1977).

CHAPTER 4. PHYTOPLANKTON

A biotic community is defined as an association of populations of microorganisms, plants, and animals. A biotic community and the physico-chemical environment in which it exists constitute an ecosystem. Complex interrelationships exist between the different groups of organisms and the pool of nutrients in the environment. Knowledge of the basic relationships and interdependencies among the three major groups of organisms (bacteria, plants, animals) and the abiotic environment are essential to the understanding of an ecosystem. Of particular interest to ecologists and managers are the trophic dynamics (relating to nutrition) of an ecosystem.

Green plants are autotrophic organisms or primary producers which can synthesize complex organic carbon compounds from simple inorganic substances. This process is known as photosynthesis and involves the conversion of carbon dioxide and water into simple sugars by a chlorophyll mediated chemical reaction. The simple sugars produced are then converted into complex substances (starches, oils, etc.) and stored as food reserves in the plant cells. In estuaries, phytoplankton are primarily responsible for this photochemical reaction, and their abundance in the aquatic ecosystem at a particular time is referred to as the standing crop of producers. Other living organisms, including most animals and decomposers (bacteria and fungi), are termed heterotrophic organisms, or consumers, because they require prefabricated complex compounds for their nutrition.

Because of their capacity to photosynthesize, plants occupy the base of almost all food chains. There are two basic food chains in estuarine environments. In one, rooted angiosperms and epiphytes are the primary producers, and in the other, phytoplankton are the primary producers (Russell-Hunter, 1970). In either case, the generated plant tissues are fed upon either directly by grazing (herbivory), or indirectly by feeding on dead plant materials and decomposers (detritivory). There may be several steps involved in a single food chain. For example, a single food chain may include a diatom species, a herbivorous zooplankton species, two predaceous zooplankton species, a smaller fish, and a larger fish. The production of fish and invertebrate tissue in an estuary or salt marsh is obviously directly related to the productivity of the green plants. Consequently, in order to understand fluctuations in the populations of zooplankton, epibenthic and benthic organisms and fish, it is also necessary to understand primary productivity in the environment.

Phytoplankton represent a high proportion of the standing crop of primary producers in estuaries and salt marsh creeks. Phytoplankton are microscopic aquatic plants which are primarily transported by tidal and wind driven currents. Phytoplankton species are classified according to life cycle characteristics, size, and location in the water column. Holoplankton refers to species that are planktonic throughout their life cycle. Meroplankton describes species which spend a portion of their life cycle as plankton. Tychoplanktonic species are benthic microalgae which may become suspended in the water column by turbulent forces.

Size classes of phytoplankton include ultraplankton (<5μm), nanoplankton (5-75μm) (Smith, 1977) and net plankton (those phytoplankters which are retained in a standard phytoplankton net with a 75μm mesh). Although net plankton are the most conspicuous members of the phytoplankton community, recent research indicates that ultraplankton and nanoplankton may be responsible for the majority of primary productivity in estuarine and salt marsh areas. Van Valkenburg and Flemur (1974) found that phytoplankton less than 10μm in size were more abundant than the net plankton during all seasons. Nanoplankton and ultraplankton species represented 55 to 100% of the total productivity, as determined by studies of radioactive carbon uptake. In the Chesapeake Bay, McCarthy et al. (1974) found that small planktonic species (<35μm) accounted for 56.6 to 89.6% of the productivity. The abundance of nanoplankton was not related to the salinity gradient, indicating the importance of this group to the entire estuarine ecosystem.

Pelagic phytoplankton refers to species found in the water column, and benthic phytoplankton are associated with substrates. Phytoneuston are located at or near the air/water interface. Recent work indicates that phytoneuston is an important component of the total estuarine phytoplankton and contributes a disproportionately large share to the total primary productivity (Manzi et al., 1977). Phytoneuston are also of ecological significance in disturbed systems because they are the first phytoplanktonic component affected by chemical spills (Sandifer et al., 1980).

Despite wide fluctuations in environmental factors, estuaries and salt marshes represent highly productive areas for phytoplankton. In fact, salt marshes are among the most productive natural areas on earth

(Schelske and Odum, 1962). Zingmark (1977) estimated the annual rate of benthic algal production in nearby North Inlet, South Carolina to be 685gC/m^2/yr. Values of 4-9gC/m^2/yr determined by Steele and Baird (1968) for an intertidal sandy beach contrast sharply to these estuarine mud-flat values.

Estuarine, salt marsh, and coastal marine phytoplankton belong to several plant divisions including Cyanophyta, Chlorophyta, Euglenophyta, Bacillariophyta, Chrysophyta, Cryptophyta, Pyrrhophyta (for complete lists of phytoplankton species refer to Sandifer et al.,1980 and Manzi and Zingmark, 1978). Benthic marine algae primarily belong to the Divisions Cyanophyta and Chlorophyta. Dominant members of the estuarine phytoplankton community include members of the Divisions Bacillariophyta (golden-brown algae) and Pyrrhophyta.

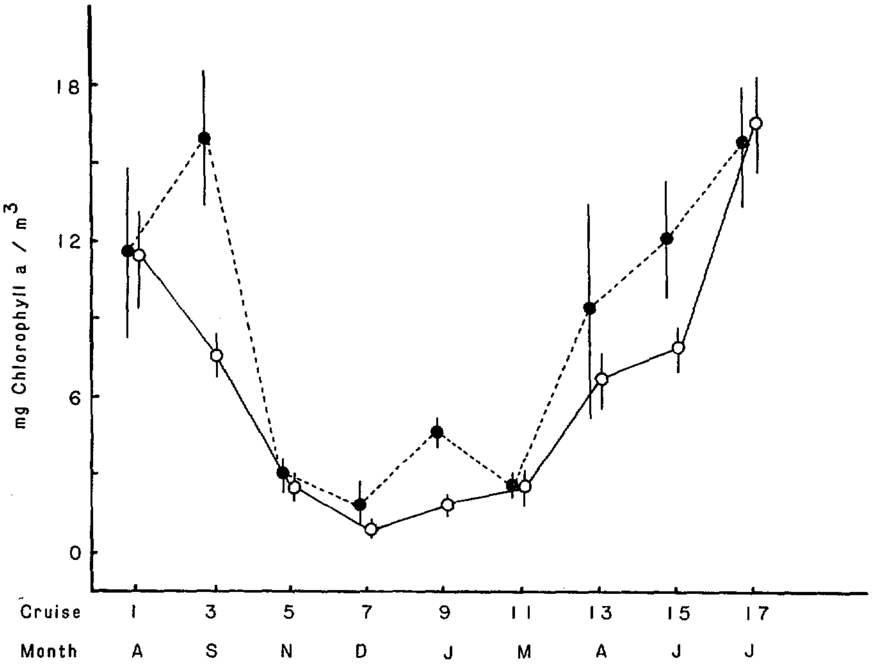
Diatoms (Division Bacillariophyta) are considered to be very important in the cycling of energy in natural waters and are often regarded as the most important autotrophs in estuarine and coastal marine waters. Diatoms are unicellular, possess cell walls made of silica, store food substances as carbohydrates or oils, and are abundant in the water column and attached to substrates. Diatoms are constructed of two siliceous valves which overlap in a pill-box configuration. They are divided into two major groups based on the morphology of these valves; centric diatoms have a valve that radiates outward from a central point and pennate diatoms are boat shaped in form.

Dinoflagellates belong to the Division Pyrrhophyta. They possess two flagella, are motile, and are either autotrophic (absorb nutrients in the water column) or heterotrophic (feed upon other organisms). Some species are bioluminescent and others are known to produce the toxins that are associated with red tides.

There are four principal methods of determining primary productivity in aquatic ecosystems: radioactive tracer techniques, rate of oxygen production as a measure of net production over a period of time, direct counting of individual plant cells, and assessment of total chlorophyll *a* content of a measured volume of water (Russell-Hunter, 1970). The productivity values obtained reflect the total standing crop of phytoplankton present in the water. Direct counting and identification of individual plant cells is the only method capable of assessing the contribution of diatoms, dinoflagellates, and other important components to the phytoplankton standing crop. Unfortunately, this tedious and time consuming method is not feasible in a study of the magnitude of the present one.

Assessments of chlorophyll *a* concentrations were used as indicators of primary productivity in this study. Determination of chlorophyll *a* is a rapid chemical method for quantifying the amount of living plant matter in the water column, but the relationship between living organic plant material and the quantity of plant pigment is highly variable, depending upon the species composition of the phytoplankton in the water as well as their state of nutrition (Strickland and Parsons, 1972). Despite this limitation, assessment of chlorophyll *a* still serves as a useful tool, providing a relative index of seasonal and diurnal changes in the standing crop of phytoplankton.

Values recorded for surface chlorophyll *a* in SJ and NMF represent a bimodal pattern with peaks occurring in late summer and winter (January) (Fig. 4-1). Highest concentrations of surface chlorophyll *a* occurred in September at NMF (16.0 mg/m^3) and July at SJ (14.9 mg/m^3). Lowest concentrations of surface chlorophyll *a* occurred in December at NMF and SJ (1.9 mg/m^3 and 1.7 mg/m^3, respectively). Highest concentrations of bottom chlorophyll *a* occurred in July at NMF and SJ (16.6 mg/m^3 and 13.3 mg/m^3, respectively) and lowest values occurred in December at NMF and SJ (1.0 mg/m^3 and 1.6 mg/m^3, respectively). Concentrations of chlorophyll *a* at both creeks were generally higher in surface water samples than bottom water samples. The January peak in chlorophyll *a* concentrations at both NMF and SJ was observed only in surface samples. Bottom chlorophyll *a* concentrations in SJ in January showed only a slight increase over adjacent sampling dates; no increase was observed in values recorded for NMF. The January peak probably represented a phytoplankton bloom involving relatively few species. Higher concentrations of chlorophyll *a* in the surface samples in both creeks reflected the greater contribution of phytoplankton in the euphotic zone to primary productivity. One interesting aspect of the chlorophyll *a* data is the absence of a large spring phytoplankton bloom, which is almost certainly a reflection of the sampling regime. Due to the ephemeral nature of the spring phytoplankton bloom, there is a high probability that sampling at six week intervals missed the bloom entirely. High concentrations of chlorophyll *a* in late summer and fall samples are probably annual events which reflect optimal conditions of solar radiation, temperature and nutrient availability. The abundance of phytoplankton in summer and fall samples is expected to be reflected in the ultimate population sizes of zooplankton during the period.



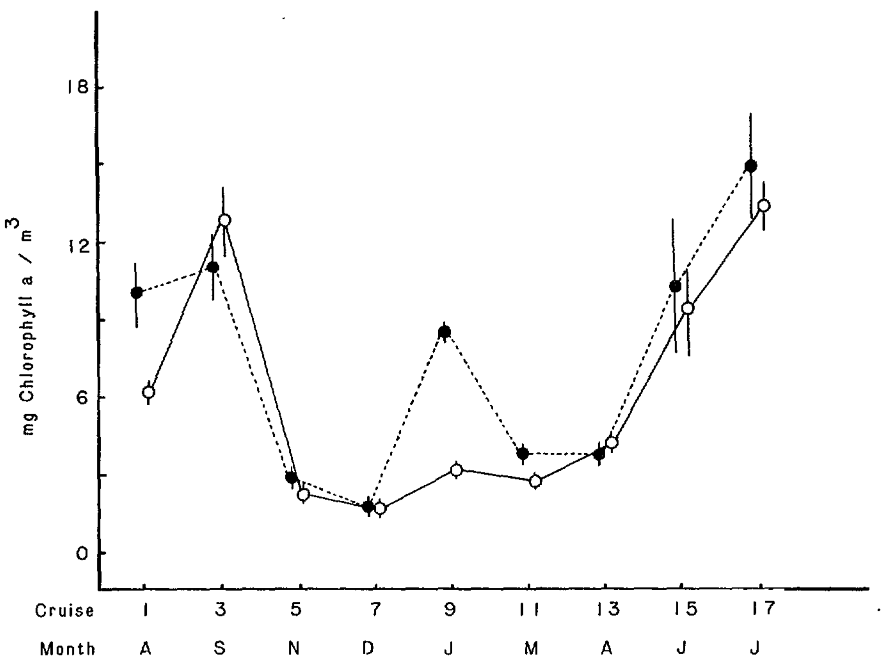


Figure 4-1. Mean surface (above) and bottom (below) concentrations of chlorophyll *a* at NMF (dark circle) and SJ (open circle) Creeks. Vertical lines through the circles indicate plus or minus the standard error.

Marshall (1980) described a bimodal pattern of phytoplankton population peaks with fall and spring maxima for lower Chesapeake Bay and Old Plantation Creek (a salt marsh intertidal creek). He found that creek waters had a greater assortment of flagellates, smaller diatoms typically associated with mud flats and vegetation within the creek complex, and representatives from other phytoplankton taxa.

A wide array of factors affect abundance and succession of phytoplankton in estuaries and salt marshes, and are summarized by Rice and Ferguson (1975) (Table 4-1). Seliger et al. (1981) found that patchiness (disjunct distribution) of phytoplankton and chlorophyll *a* in Chesapeake Bay was related to the formation and maintenance of frontal and interfrontal systems. Density flow forcing was responsible for the retention of different phytoplankton populations within different regions of the Bay. Toner (1981) demonstrated a strong statistical relationship between two factors (wind and solar energy) and the standing crop of phytoplankton in Mount Hope Bay, Massachusetts. Wind affects phytoplankton production by maintaining phytoplankton in the water column and retarding settling, resuspending nutrients trapped in the sediments, and circulating phytoplankton throughout the euphotic zone where photosynthesis occurs. Therriault and Platt (1981) found that wind speeds (≥ 5 m/s) resulted in a uniform spatial distribution of phytoplankton. Patchy distributions during periods of low wind speeds (≤ 5 m/s) were related to differences in production efficiency which was linked to the physico-chemical characteristics of the environment. Temporally related variables, including tidal flushing and diurnal changes in photosynthetic rates, may often be the most important determinants of phytoplankton abundance and primary

Table 4-1. Natural and man-imposed conditions which determine levels and rates of change of factors affecting abundance and succession of estuarine phytoplankton (Rice and Ferguson, 1975).

Factors	Natural Conditions	Man-imposed Conditions
Salinity	Precipitation, runoff, evaporation, circulation of water	Water impoundment, channelization, dredge and fill, mosquito ditching
Temperature	Latitude, season, weather, time of day, circulation of water	Heated effluent, dams, canals and waterways, stream channelization
Light Intensity		
At surface	Latitude, season, weather, time of day	Air pollution - smog
Below surface	Reflection, absorption, scattering	Dredging, waste dumping, erosion
Nutrients	Drainage, runoff, circulation of water, sediments	Sewage and industrial wastes, urban and agricultural drainage, erosion
Metabolites	Living and dead plants and animals	Sewage, urban and agricultural drainage, erosion
Toxic Substances		
Petroleum	Deposits	Leads and spills during drilling, transport, storage, use of disposal
Radionuclides	Primordial deposits, cosmic-ray produced	Fallout, nuclear power reactors, other releases
Heavy Metals	Terrestrial deposits, sediments, land drainage	Industrial and domestic wastes, mining, erosion
Synthetic Toxicants		Industrial,agricultural, domestic use

productivity (Moll and Rohlf, 1981). Baillie and Welsh (1980) emphasized the importance of tidal resuspension on the distribution of intertidal algae (an important contributor to primary productivity) in an estuary on Long Island Sound.

Many studies have examined the relationship between phytoplankton and zooplankton. Zooplankton grazing pressure acts to shape the general form of the chlorophyll profile in the ocean (Longhurst, 1976; Herman and Dauphinée, 1979; Ortner, Wiebe, and Cox, 1980; Longhurst and Herman, 1981). Zooplankton biomass and fecundity are strongly related to phytoplankton biomass in lakes and estuaries (Comita and Anderson, 1959; McCauley and Kalff, 1981; Toner, 1981). Growth and longevity of zooplankton have also been shown to be limited by nanoplankton availability (Vijverburg, 1976).

Water samples collected during major cruises were also analysed for phaeo-pigment concentrations. Highest surface phaeo-pigment concentrations were recorded in July at NMF (5.8 mg/m^3) and September in SJ (4.8 mg/m^3) (Fig. 4-2). Lowest surface phaeo-pigment values occurred in December at both NMF and SJ (1.1 mg/m^3 and 1.2 mg/m^3, respectively). Highest bottom phaeo-pigment values were recorded in April at NMF (6.5 mg/m^3) and September at SJ (7.9 mg/m^3). Lowest values occurred in January at NMF and SJ (0.6 mg/m^3 and 1.3 mg/m^3, respectively).

Degradation products of chlorophyll may constitute a significant portion of the total green pigments in the water column. Typically, phaeophytin and phaeophorbide (collectively termed phaeo-pigments) represent the greatest percentage of chlorophyll degradation products (Strickland and Parsons, 1972). Determination of phaeo-pigments serves as a useful

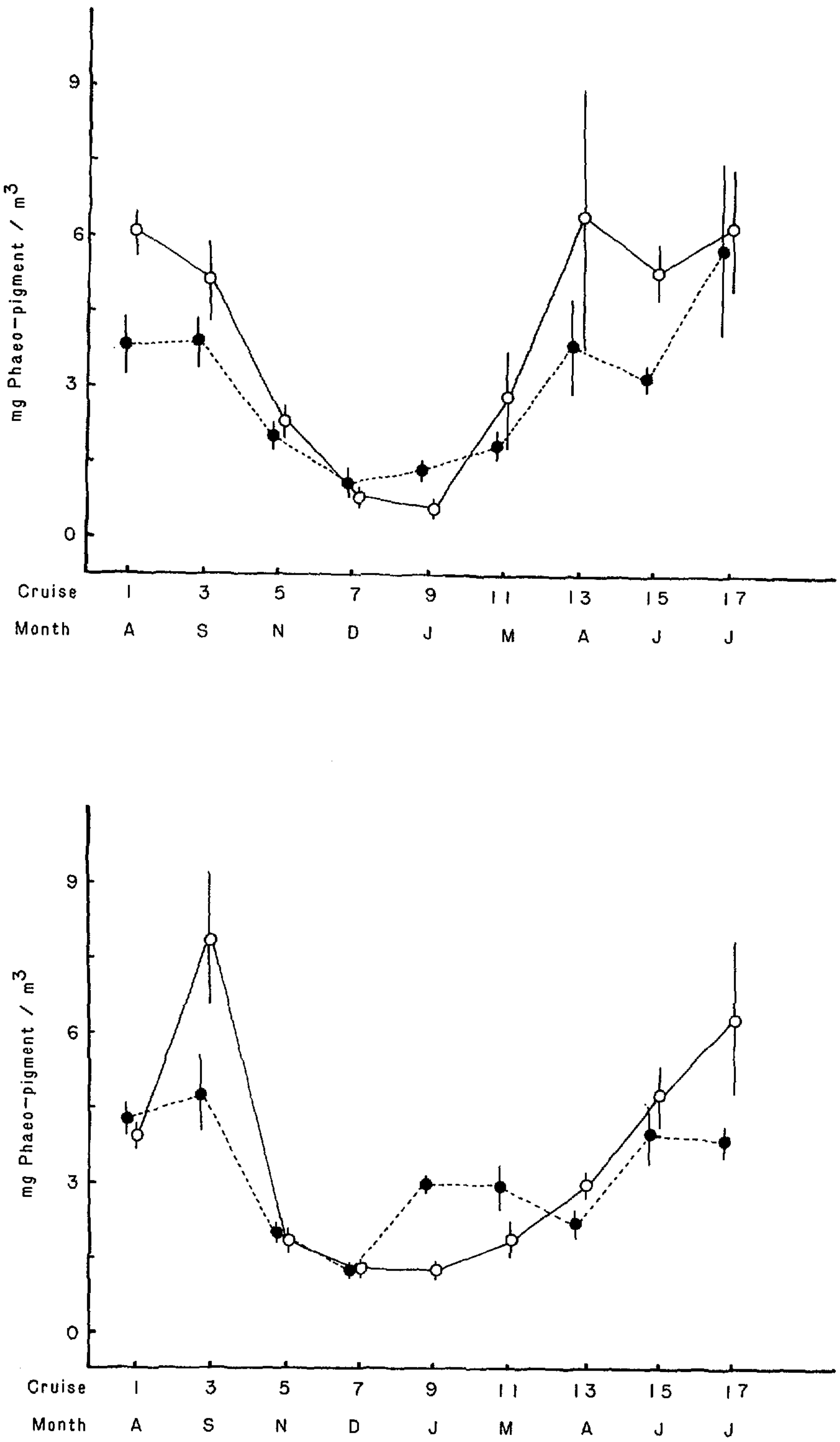


Figure 4-2. Mean surface (above) and bottom (below) concentrations of phaeo-pigments at NMF (dark circle) and SJ (open circle) Creeks. Vertical lines through the circles represent plus or minus the standard error.

tool in determining relative rates of phytoplankton turnover. High concentrations of phaeo-pigments in the water would be expected during periods of heavy grazing by zooplankton (Strickland and Parsons, 1972) and massive die-offs following phytoplankton blooms.

Seasonal patterns of phaeo-pigment concentrations closely resembled patterns described for chlorophyll *a* concentrations, and reflected the turnover of phytoplankton resulting from zooplankton grazing or natural attrition. Surface concentrations of phaeo-pigment in both creeks were lower than bottom concentrations during the warmer months (April-September), higher in January, and variable in November, December, and March. Higher concentrations of phaeo-pigment in surface waters during January reflected phytoplankton turnover of the bloom which was detected by peaks in chlorophyll *a* concentrations. Bottom concentrations increased after January as dead cells settled to the sediments and remained higher than surface concentrations during the highly productive warmer months.

CHAPTER 5. ZOOPLANKTON

Plankton (from the greek word "planktos", meaning "drifters of the sea") are microscopic organisms, both plant (phytoplankton) and animal (zooplankton), which are carried more or less passively in water currents. Although most zooplankton are capable of weak swimming movements or can control their rate of sinking and rising, they are not strong enough to move against most currents. In most aquatic habitats, the zooplankton community is a diverse assemblage of organisms containing members from many invertebrate phyla as well as young stages of fish. The community can be subdivided into the holoplankton, which are permanent members of the plankton, and meroplankton, which temporarily exist as plankton for a limited period (usually during larval development). Zooplankton range in size from about 0.01 mm to over a meter (in the case of some jelly-fish), but most of them are under 1.0 mm, and the animals discussed in this chapter rarely are over 1 cm in longest dimension.

Many zooplankton, especially the smaller forms, are herbivorous, feeding on microscopic phytoplankton (Deason, 1980; Ryther and Sanders, 1980). Studies of feeding in zooplankton (e.g. Heinle et al., 1977) have revealed, however, that many are also detritivores, which feed on dead organic particles or the layers of decomposers surrounding such particles. In addition, many zooplankton are predaceous and feed on smaller zooplankton (e.g., Cooper, 1980; Pearre, 1981). Several studies have demonstrated that many species are in fact generalists which can switch their mode of feeding between herbivory, carnivory and detritivory, depending upon which food sources are most available (e.g., Lonsdale et al., 1978). Recent evidence (Porter, 1976; Epp and Lewis, 1981) has even implied that zooplankton have symbiotic relations with some phytoplankton, gaining nutrition while providing shelter and/or nutrients.

The zooplankton in turn form a vital link in aquatic food chains, transferring energy from phytoplankton or detritus production to higher trophic levels, such as fish and shellfish. The importance of this link cannot be ignored, since most commercially important fish and shellfish have young or larval stages which are members of, and predators on, the zooplankton community. Adults of most species are also linked to the zooplankton, either by feeding directly on them or on species which do. Impacts of human activities on zooplankton can therefore influence productivity or survival of commercially important species by affecting their young or the food of their young, as well as the adults themselves.

Zooplankton are usually distributed in patches in aquatic environments. Within a given water mass, they are capable of vertical and horizontal movement, and may change their local distribution quite regularly. In deep offshore waters many zooplankton undergo regular diurnal vertical migrations to the surface and back to deeper water (Russell, 1927). In shallow waters, some forms have been shown to change their vertical distribution in accordance with light or tide levels, and the abundance of such species changes drastically over a tide cycle or 24-hour period (Cronin and Forward, 1979; Stancyk, unpublished). The causes of such movements and patchiness are not well known, but factors such as phytoplankton abundance, light, turbidity, current speed and direction, and predators may all be important. One effect of plankton patchiness is that adequate representation of the community on the basis of a few samples is usually impossible, because even simultaneous replicates may be quite dissimilar. Consequently, samples taken frequently over long periods of time are necessary to adequately characterize the zooplankton community in an area.

The makeup of zooplankton communities also varies from water mass to water mass, because individual zooplankton species are sensitive to physical and biological parameters such as salinity, temperature, tides, turbidity, food availability and predators. At least seven different zooplankton communities have been identified in coastal South Carolina, including offshore, nearshore marine, estuarine, brackish impoundments, riverine, palustrine and lacustrine (Sandifer et al.,1980). Although there is overlap in species composition between these communities, each is characterized by a different suite of dominants, as well as by different proportions of meroplanktonic/holoplanktonic forms. For instance, lacustrine habitats, or lakes, are dominated by small crustaceans called cladocerans, and have few larval forms, while nearshore marine systems are dominated by a few species of copepods and a large meroplanktonic component.

Because of its diversity and the wide size range of its members, any zooplankton community cannot be characterized completely with just one type of sampling gear. Meshes of nets select for certain sizes within the community, letting smaller members pass. In addition, larger, more motile forms can detect and avoid nets, so counts of these forms are usually underestimates of their real numbers. The problem can be solved by using more than one sampling device, but this is often impossible because of limited time or funds to process samples. Most zooplankton studies therefore involve a description of some subset of the total zooplankton community, and this report is no exception. The 153 micron (μ) mesh net used in this study selected for microzooplankton (153-300μ; Unesco, 1968) and weakly swimming larvae, and undersampled such forms as the small protozoans and holoplankton larvae (nanoplankton) and the larger, stronger-swimming shrimp and fish larvae. Many of the latter group were captured in the epibenthic sled, however, and are discussed in Chapter 6. General reference works which are useful in the study of zooplankton include: Raymont (1963); Unesco (1968); and Smith (1977).

Although the Winyah Bay-North Inlet ecosystems contain a great diversity of planktonic forms (see Tables 5-1 and 9-2), there are some species or groups which tend to dominate in numbers and biomass. Crustaceans in particular are dominant forms in planktonic systems. They are members of the phylum Arthropoda, and include the familiar barnacles, crabs, shrimps, lobsters, and crayfish, as well as numerous less familiar groups, such as copepods, amphipods, isopods, mysids, and ostracods. Crustaceans are characterized by the possession of an exoskeleton, or hard outer shell, which must be shed as they grow. Most crustaceans, especially in estuarine or marine systems, protect or brood their young for part of their development, then release them as larvae. Larvae generally go through several molts or stages before becoming adults, and

Table 5-1. Relative abundance of zooplankton on major cruises at NMF and SJ. Blanks indicate no organisms were present. Abbreviations are: R = Rare (1 - 100/m^3), C = Common (101 - 1000/m^3), A = Abundant (> 1000/m^3). NMF = No Man's Friend Creek. SJ = South Jones Creek.

DATE	AUG		SEP		NOV		DEC		JAN		MAR		APR		JUN		JUL	
CRUISE NO.	1		3		5		7		9		11		13		15		17	
STATION	NF	SJ	NF	SJ	NF	SJ	NF	SJ	NF	SJ	NF	SJ	NF	SJ	NF	SJ	NF	SJ
Copepods:																		
Acartia tonsa	A	A	A	A	C	C	C	R	C	C	C	R	A	A	A	A	A	A
Acartia copepodids	A	A	A	A	C	C	C	C	R	R	R	R	A	A	A	A	C	R
Centropages hamatus							R	R	R	R	R	R	R	R				
C. typicus	R																	
C. furcatus	R	R	R															
Eurytemora affinis						R	R		R	R	R	R						
Labidocera aestiva	R	R	R		R	R				R							R	R
Parvocalanus crassirostris	A	A	A	A	C	C	C	C	C	C	C	R	C	C	A	C	C	C
Pseudodiaptomus coronatus	C	C	C	C	C	R	R	R	R	R	R		C	C	C	R	C	C
Tortanus setacaudatus		R				R												
Temora turbinata	R	R	R	R	R	R									R		R	R
Corycaeus sp.					R	R	R	R	R					R		R		R
Oithona colcarva	C	C	C	R	C	C	C	R	C	C	R	R	C	C	R	R	C	C
Saphirella sp.	R	R	R	R	R	R	R	R	R		R		R	R	R	R	R	R
Oncaea venusta		R	R		R	R			R	R							R	R
Euterpina acutifrons	C	C	R	R	C	C	C	R	R	R		R	R	R	R	R	R	R
Other harpacticoids	R	R	R	R	R	R	R	R	R	R	C	C	C	R	R	R	C	C
Copepod nauplii	C	C	C	C	C	C	R	C	A	C	R	R	C	R	C	C	C	C
Copepodids	R	R	R	R	R	R	R		C	C	C	C	R	R	R	R	R	R
Meroplankton:																		
Coelenterate larvae	R	R	R	R	R	R	R			R	R	R		R	R	R		R
Cyphonautes larvae(Bryozoans)	R	R	R	R	R	R		R	R				R	R	C	C		R
Actinotroch larvae(Phoronida)															R			
Trochophore larvae			R		R	R		R			R		R		R	R		
Polychaete larvae		R	R	C	R	C	R	R	R	R	R	R	R	C	R	C	R	C
Gastropod veligers	C	C	C	C	C	C	R	R	R	R			C	R	C	A	C	C
Bivalve larvae	R	R	R	R	R	R	R	R	R	R		R	R	R	C	R	R	R
Echinoderm larvae(starfish, sea cucumber)			R	R	R	R				R					R	R		R
Pluteus larvae(ophiuroids, echinoids)			R		R				R						R			
Barnacle nauplii	C	C	C	C	A	A	C	A	C	A	C	A	A	A	C	C	C	A
Barnacle cyprids	R	R	R	R	R	R	R	R	R	R	R	R	R	R	C	R	R	R
Porcellanid crab zoeae		R											R					
Crab zoeae (other)	A	A	C	C	R	R				R			R	R	A	A	C	C
Crab megalopae	R	R	R		R	R									R	R	R	R
Palaemonetes juveniles			R			R										R		
Shrimp larvae (other)	R	R		R		R							R	R	R	R		R
Decapod larvae (other)	R	R	R	R	R										R	R	R	R
Fish larvae	R	R	R	R	R	R									R	R	R	R
Others:																		
Hydroid polyps	R	R	R						R						R	R	R	R
Cladocerans	R				R						R		R			R		R
Ostracods	R	R	R		C	R	R	R	R	R	R	R	R	R		R		R
Mysids	R	R			R	R			R	R	R	R	R			R	R	
Cumaceans																R		
Gammarid amphipods	R	R	R		R	R			R	R		R				R	R	
Caprellid amphipods		R	R													R		R
Isopods	R	R	R	R	R	R			R	R				R	R	R	R	R
Lucifer	R	R	R	R												R		
Acetes		R																
Chaetognaths	R	C	R	R	R	R			R						R	R	R	R
Appendicularians	R	R	R	R	R	R	R							R	R	R	R	R
Others	R	R	R	R	R	R	R		R	R		R	R	R	R	R	C	C
Total Zooplankton Categories	35	39	38	28	36	37	22	19	28	26	19	19	25	25	32	38	29	35

make up a large component of the meroplankton.

Among the holoplankton, members of the Class Copepoda are usually the most common forms. There are at least 7500 species of copepods, divided into seven orders, the most common of which are Calanoida, Harpacticoida and Cyclopoida. Copepods generally have short, cylindrical bodies (Fig. 5-1a); none of the species found in this study was longer than 2 mm. They have numerous appendages which they use for feeding and swimming. They move with short jerky motions and can maintain themselves in the water column for short periods by extending their antennae laterally to prevent sinking. The four feeding types mentioned previously (herbivores, detritivores, carnivores, omnivores) are all found in the Copepoda.

Copepods reproduce sexually; some shed their eggs singly into the water, but most enclose them in ovisacs containing up to 50 eggs each, carried near the abdominal portion of the body. The eggs hatch as nauplius larvae (Fig. 5-1b) and go through 5-6 naupliar stages (molts) before becoming copepodids, which resemble adults but have fewer appendages. There are five copepodid stages before the adult, and the entire course of development can take from one week to a year, depending upon the species. Most free-living species have a maximum life span of 6 months to a little over 1 year.

Calanoids are the most characteristic group of marine holoplankton and 14 species have been found in the North Inlet-Winyah Bay area, of which ten (Tables 5-1 and 5-2) are fairly common (Lonsdale and Coull, 1977; Ferrell, unpublished). In particular, *Acartia tonsa, Parvocalanus*

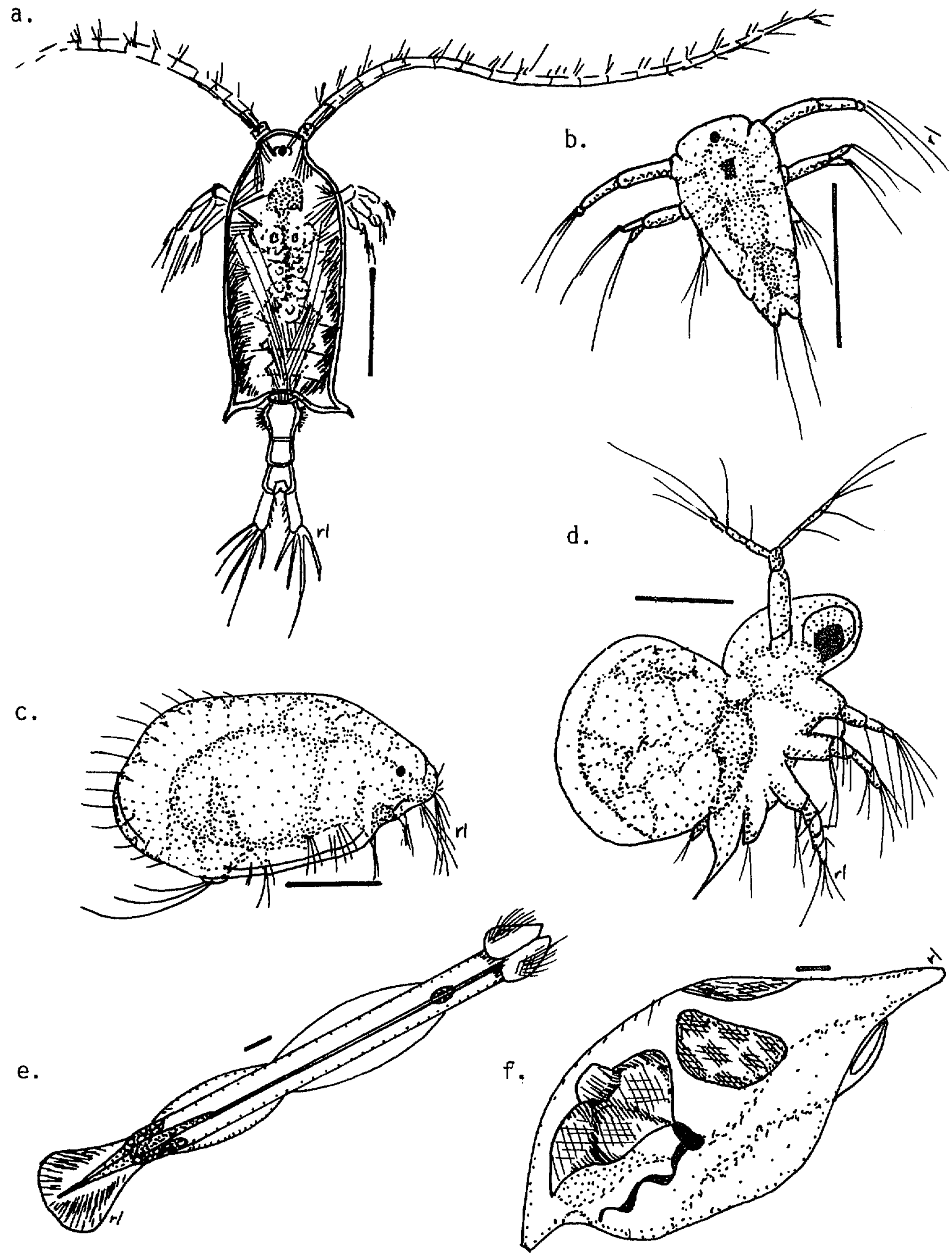


Fig. 5-1. Holoplankton of Winyah Bay, S.C.: a. calanoid copepod; b. copepod nauplius; c. ostracod; d. cladoceran; e. chaetognath; f. appendicularian in its house. Scale bar represents 0.2 mm.

(Paracalanus) crassirostris and *Pseudodiaptomus coronatus* are characteristic of the study area (Tables 5-1 and 9-2; Lonsdale and Coull, 1977), as well as other estuarine and coastal environments in the east and southeast (Bowman, 1971; Alden, 1977; Sandifer et al. 1980). Calanoids are found throughout the world, and can be recognized by their relatively large size, torpedo shape, and long first antennae (Fig. 5-1a).

Cyclopoid copepods are a little smaller than calanoids, and have a generally wider head region tapering towards the abdominal region. They also have shorter first antennae. At least seven species of cyclopoids have been identified in the North Inlet-Winyah Bay area (Lonsdale and Coull, 1977; Ferrell, unpublished), of which *Oithona colcarva, Corycaeus sp., Saphirella sp.* and *Oncaea venusta* are fairly regular in occurrence (Tables 5-1 and 9-2). These genera were also common in the Cape Fear River estuary (Copeland et al. 1974), and have been recorded previously from North Carolina, South Carolina and Georgia waters (Sandifer et al. 1980).

Fifty-three species of harpacticoid copepods have been identified in the Winyah Bay-North Inlet region (Coull, 1978), but most of these are meiofaunal forms which live within or on the sediments. Although they are an extremely important part of the benthic community, relatively few harpacticoids occur in the plankton. Several species may spend part of their adult life as temporary plankton (M. Palmer, unpublished), but the most regularly occurring holoplanktonic species is *Euterpina acutifrons*. *Euterpina* is cosmopolitan, and has been found in estuarine and coastal waters all along the east coast and the Gulf of Mexico (Alden, 1977).

Another crustacean group which is common in the holoplankton, although not nearly as abundant as copepods, are members of the Class Ostracoda (Fig. 5-1c). Ostracods are also called seed shrimps, and are found in freshwater, marine, and estuarine habitats. There are approximately 2000 living species worldwide, which range in size from 1 to several millimeters. Ostracods have bivalved shells, and look very similar to small clams, except they have numerous appendages protruding from the shell. Most species are benthic, but a few live in the water column, feeding on detritus and phytoplankton. Although they were not identified to species, ostracods occurred in the study area nearly year-round (Tables 5-1 and 9-2).

Cladocerans, or water fleas, are also members of the holoplankton (Fig. 5-1d). They feed primarily on phytoplankton and protozoans, and carry their eggs in a brood chamber. Development is direct, with no larval forms being released into the plankton. Cladocerans are members of the Class Branchiopoda, and are especially characteristic of fresh waters. Nevertheless, several genera, including *Podon*, *Evadne* and *Penilia* occur in nearshore and estuarine waters, and were found in this study (Tables 5-1 and 9-2).

Several other crustacean groups are represented in plankton collections, but they were rarely captured effectively in our microzooplankton nets. These include many small shrimps, isopods, amphipods, mysids, cumaceans, and stomatopods. Many of these groups were captured in the epibenthic sled collections, and their occurrence and biology are discussed in Chapter 6.

There are three commonly-occurring holoplankton groups which are not crustaceans: chaetognaths, appendicularians, and ctenophores (see Chapter 6). Chaetognaths, or arrowworms, are voracious predators in the plankton, consuming up to 37% of their body weight per day (Green, 1968). Their diet consists chiefly of copepods, but they are also known to take larval fish. They move by combinations of swimming and floating, and resemble feathered darts in appearance (Fig. 5-1e). They are clear, and average 3 cm or less in length. Pierce and Wass (1962) listed four species which were common inshore, including *Sagitta enflata, S. helenae, S. hispida* and *S. tenuis*.

Appendicularians are members of the subphylum Urochordata, Class Larvacea. They are small (1-5 mm) soft-bodied organisms who build mucus "houses" which contain fine-mesh filters capable of capturing bacteria-sized particles (Fig. 5-1f). Thus, they may be extremely important in the zooplankton food chain, passing energy from bacteria and nannoplankton to higher trophic levels. Costello (1981) found that appendicularians in the North Inlet-Winyah Bay area occur in greatest densities offshore, with inshore abundances changing according to stage of tide and season. Three species, *Oikopleura dioica, O. longicuada* and *Appendicularia sicula* were found, with *O. dioica* being most abundant inshore.

The meroplankton, or temporary zooplankton, consist chiefly of larval stages of benthic invertebrates, and are very diverse. Meroplankton are especially abundant in nearshore (Reeve and Baker, 1975) and estuarine waters (Raymont, 1963; Green, 1968), and species composition may reflect the faunal composition of adjacent estuaries or marshes (Turner et al. 1979; Christy and Stancyk, 1981). As with holoplankton, crustaceans make up a very large component of the meroplankton.

Among the most ubiquitous crustacean meroplankton are the larvae of barnacles (Class Cirripedia), which are all sessile as adults. Barnacles are extremely common in marine and estuarine subtidal and intertidal habitats. Over 900 species have been described, with 30 or more occurring in coastal South Carolina waters (Zullo and Lang, 1978). Lang (1979) collected 11 species of barnacles in the North Inlet-Winyah Bay region, and described the larval development of 10 of them. Barnacles release their young from the mantle cavity as nauplii (Fig. 5-2a), characterized by the possession of horns on the head region and their upside down swimming habit. The young pass through six naupliar stages, during which time they feed on phytoplankton, chiefly diatoms and flagellates. Some species may be partially carnivorous, as they have been observed feeding on weakened copepods in the laboratory (T.L. Ferrell, unpublished observations).

Prior to metamorphosis to the adult stage, barnacle nauplii go through a cyprid stage. Cypris larvae (Fig. 5-2b) resemble ostracods because they have a bivalved shell. They contain cement glands, and if they find a suitable substrate, are capable of metamorphosing into the sessile adult form. If they fail to find a suitable substrate, they may defer settlement for varying lengths of time. Barnacle settlement may be quite substrate-specific, and recent work (Strathmann and Branscomb, 1979; Strathmann et al. 1981) has demonstrated that settlement in the wrong habitat can be fatal. Habitat-specific cues are often used by settling invertebrates (Meadows and Campbell, 1972), and if their abilities to sense these cues are hampered, the results can be fatal. Pearson

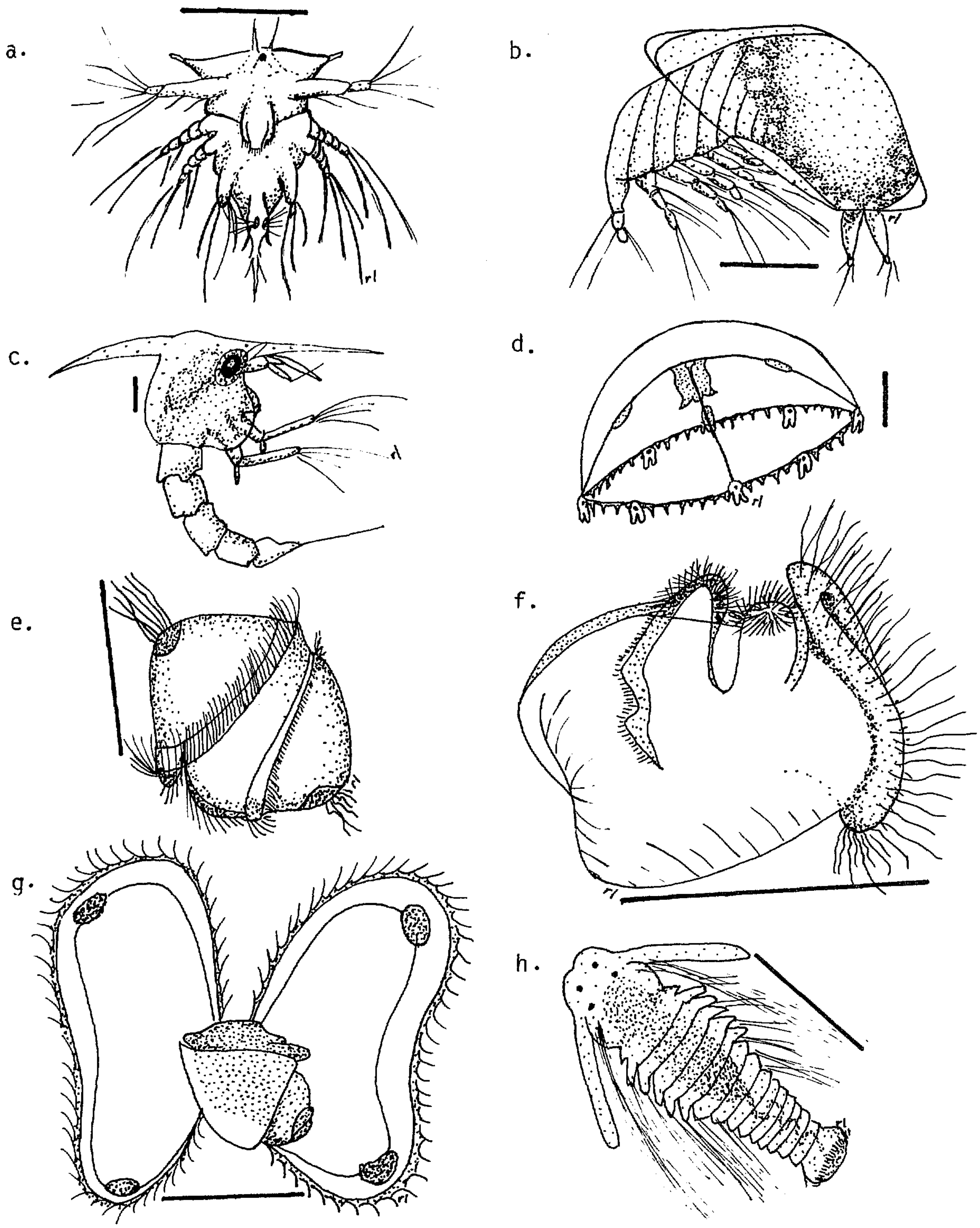


Fig. 5-2. Meroplankton in Winyah Bay, S.C.: a. barnacle nauplius; b. barnacle cyprid; c. crab zoea; d. hydromedusa; e. trochophore; f. bivalve veliger; g. gastropod veliger; h. polychaete larva. Scale bar represents 3 mm.

and Olla (1979) have recently shown that hydrocarbon fractions can inhibit the sensory abilities of adult crabs, and it is possible that numerous larval forms could also be affected by these chemicals (Olla, personal communication).

Crab larvae, called zoeae (Fig. 5-2e), are among the most well-studied and easily-recognized crustacean larvae in nearshore-estuarine areas. Considerable work has been done on the zoeae of estuarine crabs, particularly the commercially important blue crab, *Callinectes sapidus* (e.g. Sulkin et al., 1980), and the mud crab, *Rithropanopeus harrisii* (e.g. Cronin and Forward, 1979). In the North Inlet area, including South Jones and No Man's Friend Creeks, up to 95% of the crab zoeae collected belong to one of the three local fiddler crabs, *Uca spp.* (Christy and Stancyk, 1981; DeCoursey, 1979), although zoeae of at least 15-18 species of brachyuran crabs have also been identified (Christy, personal communication). Because of their numerical abundance, larvae of *Uca spp.* in North Inlet and elsewhere have been the subject of several studies (Bergin, 1981; DeCoursey, 1979; Christy, 1978). Zoeae are seasonally important predators of copepods and other small zooplankton, and molt through 3-6 zoeal stages before changing to the pre-metamorphosis megalops stage. Megalopae, although much smaller, have a morphology very similar to the adult crabs (see Fig. 6-6a), except that their abdomens are not folded under the carapace. Research on these forms indicate that megalopae of estuarine crabs move into the estuary and up tidal creeks before metamorphosis (Sandifer, 1975; Christy, personal communication). They are distributed primarily near the bottom and are strong enough swimmers to avoid smaller plankton nets, so they were captured more efficiently in the epibenthic sled, and will be discussed in Chapter 6.

Larvae of many non-crustacean organisms are also commonly found in the North Inlet-Winyah Bay plankton. Included among these are the medusa larvae of hydrozoans (Phylum Cnidaria; Fig. 5-2d), which resemble the larger, more well-known holoplanktonic jellyfish (Classes Scyphozoa and Cubozoa). Hydrozoan medusae are predaceous and occur widely throughout the system, especially in the warmer times of year.

Larvae of molluscs (especially clams and snails) and polychaete worms are also extremely abundant in nearshore and estuarine waters. The earliest larvae of both groups are small, yolky, ciliated trochophores (Fig. 5-2e) which are capable only of the weakest swimming movements. Clams (including such commercially important species as the American oyster, *Crassostrea virginica*, the Southern Quahog, *Mercenaria mercenaria*, and the Calico Scallop, *Argopecten gibbus*) and snails (such as the whelks, *Busycon spp.*, the mud snail, *Illyanassa obsoleta*, and the tulip shell, *Fasciolaria lilium*) go from trochophore to veliger stages (called bivalve and gastropod veligers [Fig. 5-2f and 5-2g], respectively). Polychaete trochophores become larvae (Fig. 5-2h) which resemble adult worms except that they have extremely long setae and are strong swimmers. These larval stages are primarily herbivorous, and may spend from 1 to several weeks in the plankton. Local molluscs and polychaetes are extremely diverse, and their larvae are very difficult to distinguish to species, so they were not classified further in this study. However, the diversity of these groups in the area makes it unlikely that peaks in abundance of bivalve, gastropod and polychaete larvae (Tables 5-1 and 9-2 ; Fig. 5-2) represent individuals of the same species.

Many other larval forms of benthic adults can be found in the North Inlet-Winyah Bay region. These include actinotroch larvae of the small phylum, Phoronida, pilidium larvae of nemerteans, cyphonautes larvae of bryozoans, and bipinnaria or pluteus larvae of echinoderms (sea cucumbers, starfish and brittlestars). Examples of these groups are illustrated in most invertebrate textbooks (i.e., Barnes, 1980) or plankton manuals (i.e., Smith, 1977). None of these larvae are extremely abundant at any one time, but together they make up a large component of the meroplankton. Their role in the plankton is poorly known, but if these populations were disturbed by pollutants, the effects on the adult populations, including the commercially important forms, could be disastrous.

Table 5-1 shows the species of zooplankton captured by cruise in No Man's Friend (NMF) and South Jones (SJ) Creeks between August, 1980 and July, 1981. Although there are 11 to 15 species of copepods and up to 27 other categories present on each cruise, only a few are dominant at any time; 5 to 8 species usually make up over 90% of the animals by number. In general, the two creeks have the same dominant species at the same times, but mean numbers and presence or absence of minor species may vary. All of the 18 species of copepods which occur with regularity in North Inlet were collected at NMF and SJ, but only two, *Acartia tonsa* and *Parvocalanus crassirostris*, were extremely abundant; they occurred in numbers at least one order of magnitude greater than any other copepod species. Only five species of copepods were year-round residents in the creeks (*Acartia tonsa, Parvocalanus crassirostris, Pseudodiaptomus coronatus, Oithona colcarva, Euterpina acutifrons*). Along with most of the other copepods, they were most abundant in spring and summer. On the other hand, some copepods were distinctly winter residents. *Centropages hamatus* and *Eurytemora affinis*, for instance, were found only between November and April, when numbers of other copepod species were lowest.

Some non-copepod forms also showed peak winter abundance, particularly nematodes. Most of the non-copepod groups were warm-season types, however, including appendicularians, chaetognaths, and larvae. Larval forms of benthic or pelagic species were often seasonal in appearance, but could become dominant organisms during periods of peak abundance. The most common larval forms were barnacle nauplii, crab zoeae, cyphonautes larvae of bryozoans, gastropod veligers, and polychaete larvae. Some of these groups (i.e. barnacle nauplii, barnacle cyprids, and polychaete larvae) were present throughout the year, which probably indicates reproduction by several species during that time.

I. HOLOPLANKTON

A. *Acartia tonsa*

As in many other eastern estuaries from Cape Cod to western Florida (Woodmansee, 1958), this species dominates the North Inlet-Winyah Bay ecosystem. In NMF and SJ, *A. tonsa* reached mean abundances of 5-6000/m^3, and formed a co-dominance during the spring and summer with *Parvocalanus crassirostris* (Fig. 5-3). *A. tonsa* abundance was usually greater in NMF than in SJ, but seasonal trends were exactly the same. *Acartia* copepodids (Fig. 5-3) followed similar trends, and together with adult *A. tonsa* they dominate the system by an order of magnitude when present. *Acartia* shows considerable seasonal variation, however,

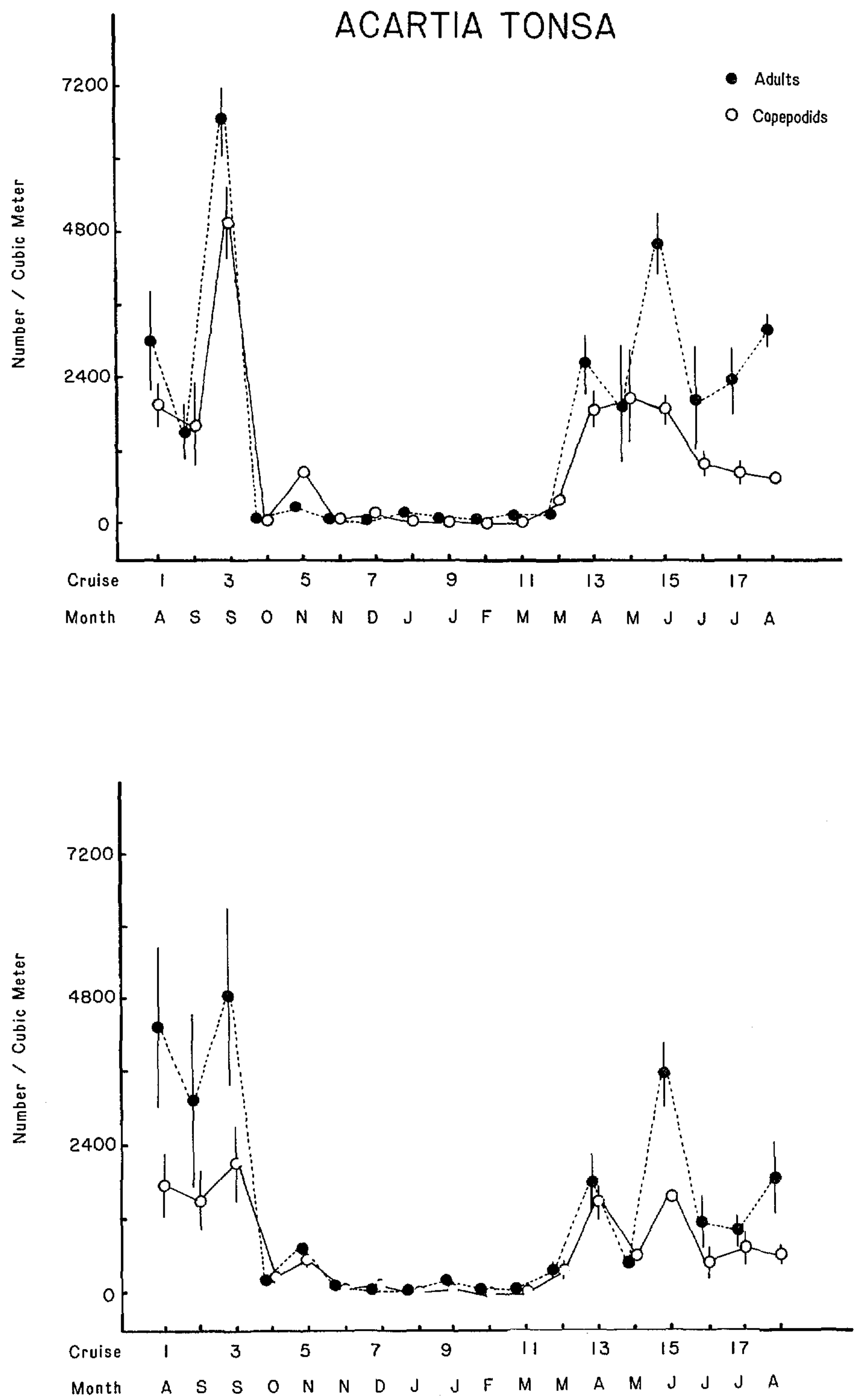


Figure 5-3. Mean densities (no./m^3) of adult and copepodid *Acartia tonsa* on cruises 1 - 18 at NMF (above) and SJ (below). Vertical lines indicate plus or minus the standard error.

and is nearly absent from both creeks during the winter months (October-March).

Acartia tonsa is a warm-water euryhaline species. It occurs in the northern part of its range only in the summer (Jeffries, 1962; Durbin and Durbin, 1981), although it is a year-round resident in Florida (Woodmansee, 1958) and North Carolina (Sutcliffe, 1948). Adults measure from 1.0-1.5 mm in length, and females have two broods (Deevey, 1948). They may go through several generations (about 37 days from egg to adult; Jeffries, 1962) in a season, and up to 11 generations a year (Woodmansee, 1958). *A. tonsa* is a true estuarine species (Bowman, 1971) with a broad salt tolerance range (Lance, 1963). It is generally found in greater numbers in bays and rivers than more open waters (Grice, 1960; Sandifer et al., 1981). In North Inlet, populations of *A. tonsa* were not significantly flushed from the estuary (Stancyk and Ferrell, unpublished); and in other estuaries have been shown to be distributed in the water column in a manner which favors retention in estuaries (Show, 1980). Trinast (1975) found that another *Acartia* species in a California estuary was also retained. *A. tonsa* is a fairly generalized feeder, and has been shown in the laboratory to consume phytoplankton, detritus, and larvae of other copepods (Lonsdale, Heinle, and Siegfried, 1978; Heinle, Harris, Ustach and Flemmer, 1977). In fact, its abundance during certain parts of the year, coupled with its predatory habits, may prevent less common, smaller copepod species populations from growing during the warm seasons (Lonsdale et al., 1978).

Lonsdale and Coull (1977) demonstrated an *Acartia tonsa* - *Parvocala-*

nus crassirostris codominance in the warm months in North Inlet; they also demonstrated that although the smaller *Parvocalanus* was more abundant year-round, *A. tonsa* dominated in biomass. This species is one of the most important copepods in the nearshore system. It is fed upon by numerous fishes (Allen et al.,1978; Durbin and Durbin,1981) and is extremely productive when it is present. Perturbations which remove *A. tonsa* from the system when it normally would be present would have significant effects on the rest of the ecosystem by removing a species which plays a central role in the zooplankton community.

B. *Parvocalanus crassirostris*

This species was the most abundant copepod year-round at SJ and NMF (Fig. 5-4). Although there were sampling periods when *P. crassirostris* numbers were quite low, there was no evidence of seasonality in the occurrence of this species. On many occasions, mean numbers would exceed those of *Acartia tonsa*, but Lonsdale and Coull (1977) demonstrated that *A. tonsa*, being larger dominated in biomass on an annual basis at North Inlet, and the relationship appears to hold at SJ and NMF. The numbers of *P. crassirostris* on any given sampling date were usually lower at SJ than at NMF (Fig. 5-4), but they usually showed peaks of abundance at the same times. An exception to this occurred in early June, 1981, however, when *Parvocalanus* numbers ranged around $3200/m^3$ at NMF, but were only about $600/m^3$ at SJ. Numbers subsequently declined at NMF, and by July the stations were once again similar.

Parvocalanus crassirostris is not as widespread as *Acartia tonsa*,

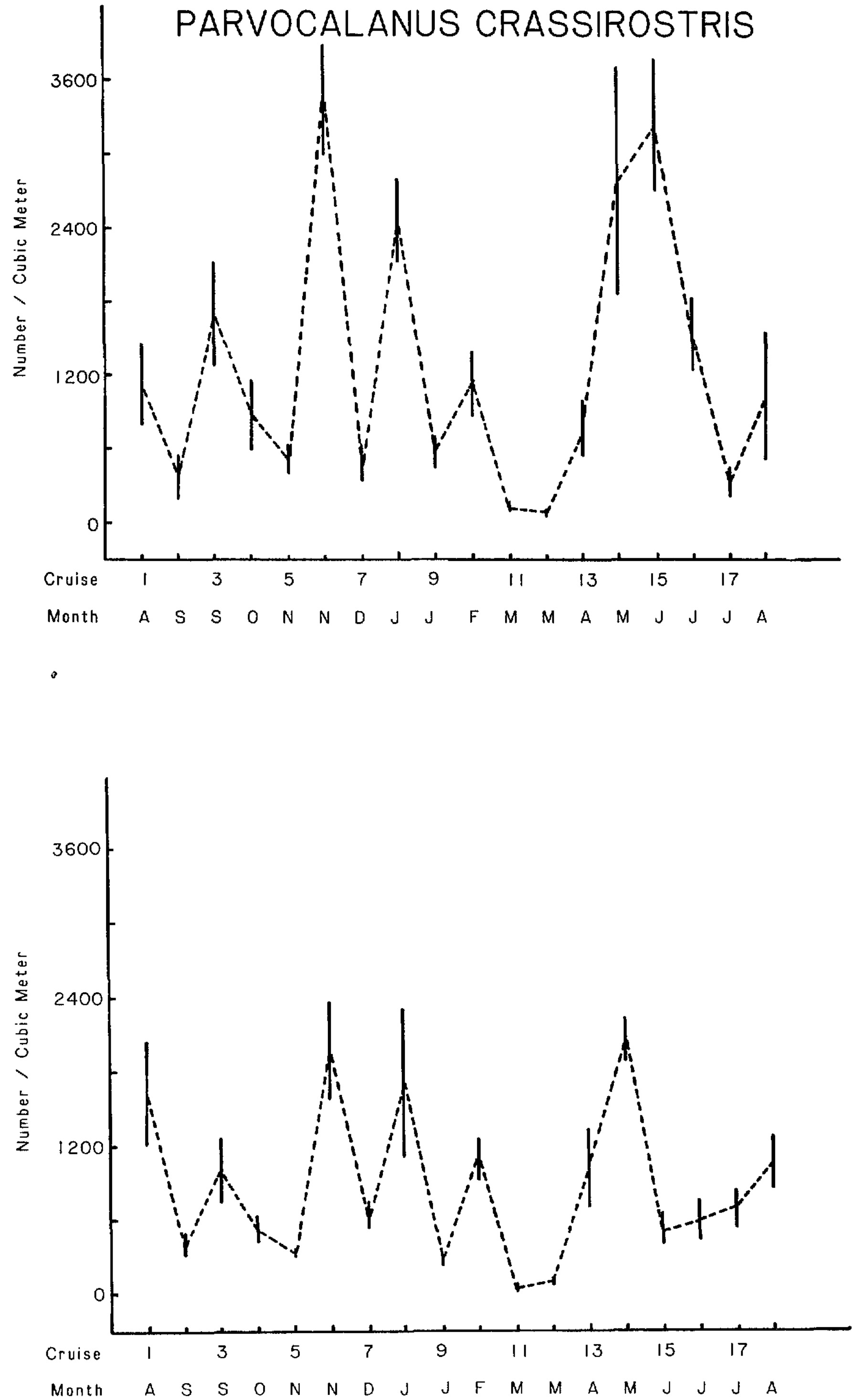


Figure 5-4. Mean densities (no./m^3) of *Parvocalanus crassirostris* on cruises 1 - 18 at NMF (above) and SJ (below). Vertical lines indicate plus or minus the standard error.

but is just as characteristic of estuarine waters. It is a distinctly coastal species, and is generally found where salinities range from about 24-37 o/oo. Most published information on *P. crassirostris* deals with populations sizes and distribution. It is among the dominant species in many nearshore or estuarine surveys from North Inlet to the Gulf Coast of Florida (Grice, 1960; Stickney and Knowles, 1976; Alden, 1977; Lonsdale and Coull, 1977). It was not abundant, however, in the Wando River in South Carolina (Sandifer et al. 1980), although its smaller size may have made its capture less likely by the nets used in that study. It is chiefly herbivorous, although not much is known about its feeding biology in the field. Although little is known of its biology other than distribution and salinity tolerance, its abundance insures that it is a large component of the diet of larval fishes and larger carnivorous crustacean larvae.

C. *Pseudodiaptomus coronatus*

This was the third most abundant calanoid copepod in the areas sampled (Fig. 5-5) but rarely reached numbers as high as 2700/m^3. Mean abundances were closer to 400/m^3, and *Pseudodiaptomus* was found in spring, summer and fall, when its abundance was greatest. Numbers were usually higher at NMF, but as with other species, peaks usually coincided between the two creeks. *Pseudodiaptomus* occurred at NMF as late as November, but was not found at SJ after early October.

Although is it quite widespread (Nova Scotia to Mississippi River; Wilson, 1932; Wright, 1936) and is characteristic of temperate marine or brackish water, *P. coronatus* is never as abundant as the aforementioned species. In the southern part of its range, it is more of a

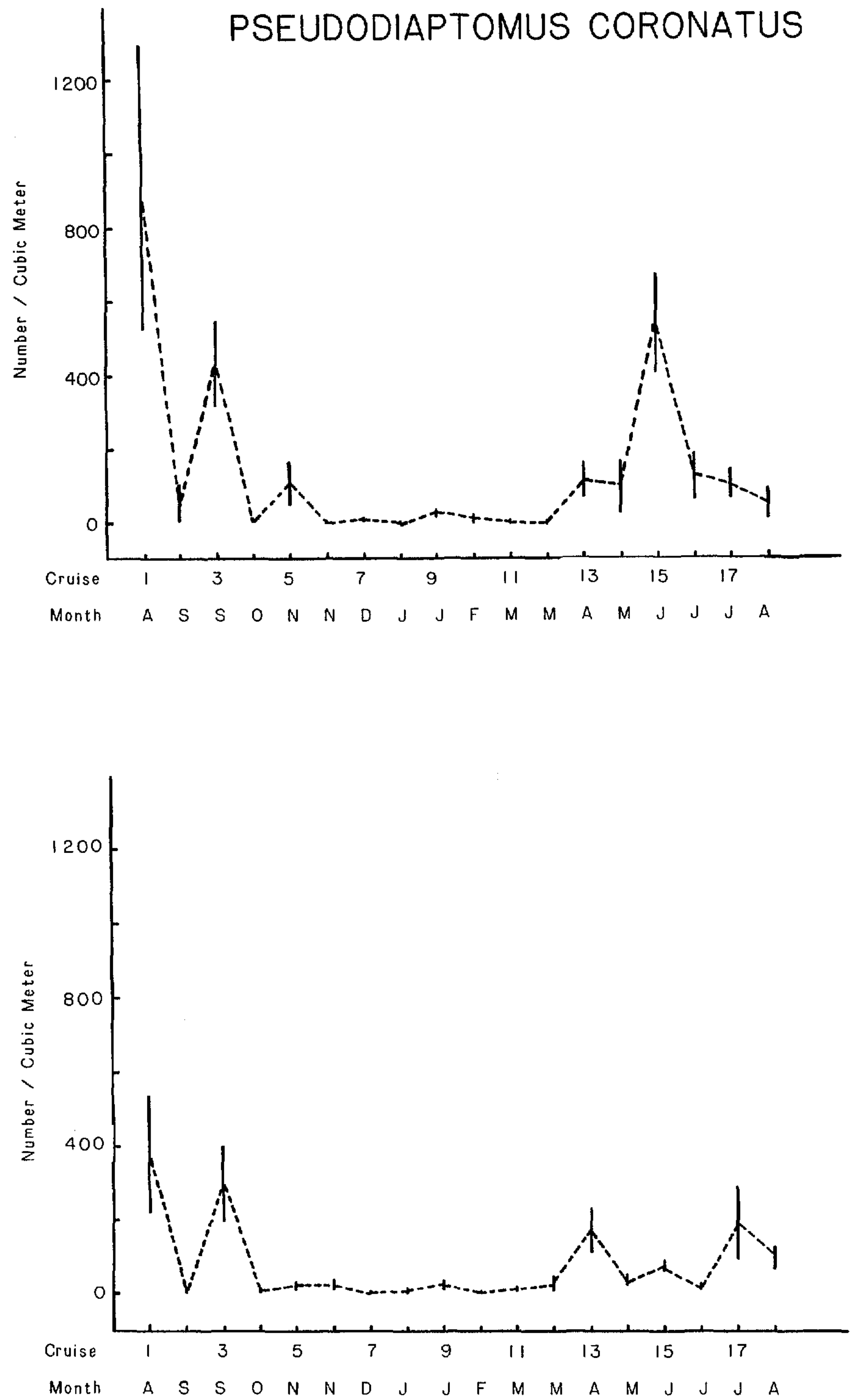


Figure 5-5. Mean densities (no./m^3) of *Pseudodiaptomus coronatus* on cruises 1 - 18 at NMF (above) and SJ (below). Vertical lines indicate plus or minus the standard error.

fall-winter species, but has peak abundances in spring and especially fall in other areas (Sutcliffe, 1948; Woodmansee, 1958; Sandifer et al., 1980). Its occurrence at SJ and NMF Creeks was different than in the mouth of North Inlet in 1975 (Lonsdale and Coull, 1977) when it had high densities from late winter through the summer.

Pseudodiaptomus coronatus is a relatively large (1.0-1.5 mm) species, which Jacobs (1961) contended was not truly planktonic, since it clung to detritus and other suspended material. Such abilities would allow it to modify its vertical and horizontal distribution, and Jacobs, in fact, found greatest concentrations of *P. coronatus* copepodites near the bottom in Doboy Sound and the Duplin River in Georgia. Such a distribution would make the species less likely to be exported from estuarine situations, and possibly more susceptible to bottom predators or to environmental hazards such as pollutants stirred from bottom sediments.

D. *Centropages hamatus*

This was the most common of three species of *Centropages* in the area, including *C. hamatus*, *C. furcatus*, and *C. typicus*. Although it was never as abundant as the calanoids previously mentioned, *C. hamatus* is distinctive in that it was a definite winter resident at SJ and NMF (Fig. 5-6). Even in winter, its occurrence was relatively patchy, with peaks occurring in November, February, and April at SJ, but only in February and April at NMF. Abundances were never as high at NMF as SJ, which is opposite from the calanoids described above.

Centropages hamatus is a robust copepod 0.9-1.35 mm in size. Its

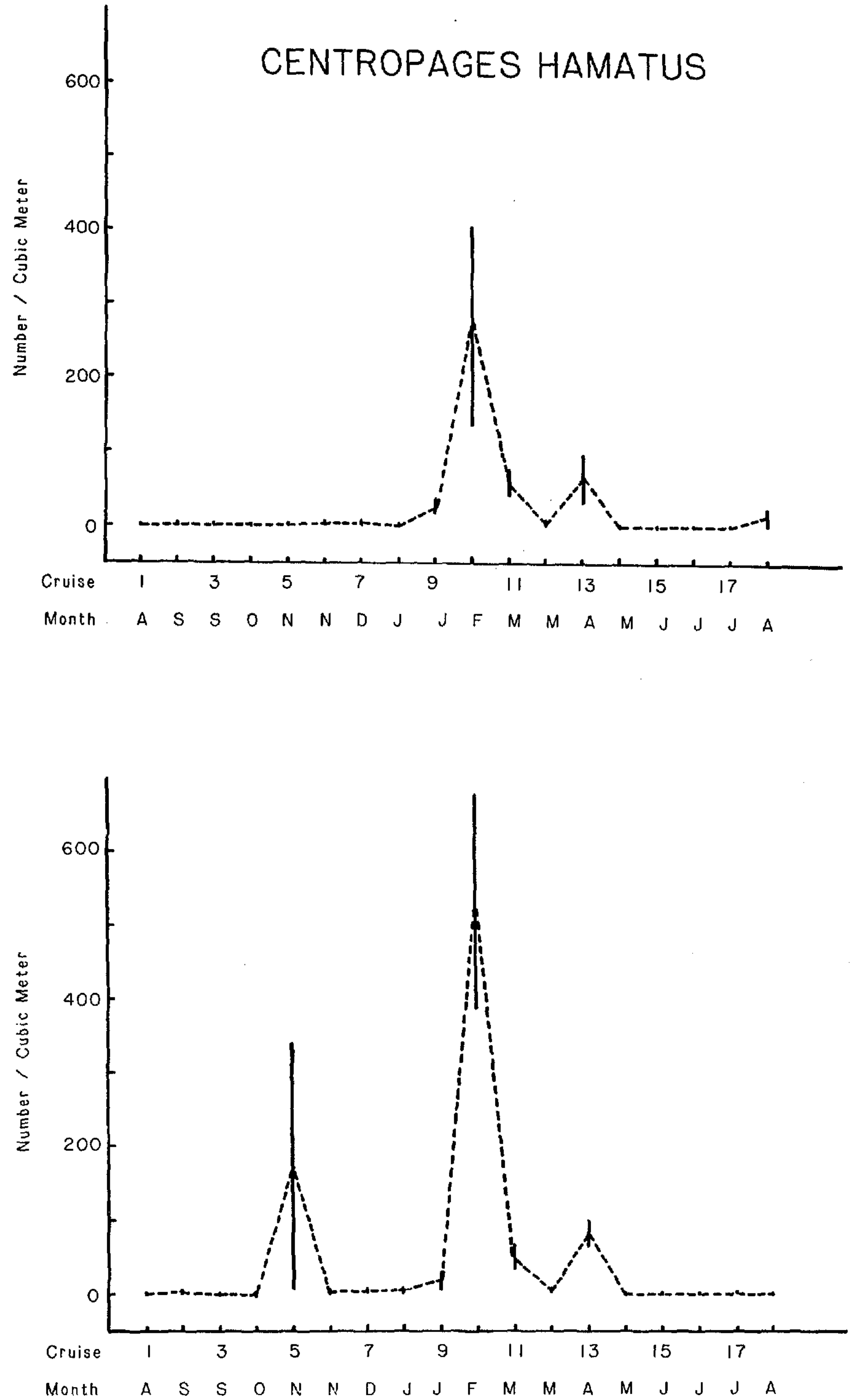


Figure 5-6. Mean densities (no./m^3) of *Centropages hamatus* on cruises 1 - 18 at NMF (above) and SJ (below). Vertical lines indicate plus or minus the standard error.

range is from the Chesapeake Bay to the Gulf coast of Florida (Wilson, 1932; Grice, 1960). It appears to be primarily herbivorous in nature (Smith, 1975; from Alden, 1977), with a winter occurrence throughout its range. Wilson (1932) suggested that *C. hamatus* is probably eaten by shad during their spring migrations, and it was one of the most abundant copepods found in the guts of larval fishes in North Carolina estuaries (Thayer et al., 1974).

E. *Oithona colcarva*

This small cyclopoid copepod was the third most abundant form in the study (Fig. 5-7). As found by Lonsdale and Coull (1977), it occurred in lower numbers in spring, and had its highest density in late fall, with a peak mean of $3720/m^3$ in November, 1980. Numbers of animals were generally similar between NMF and SJ, and peaks of abundance coincided exactly. *Oithona* is smaller than the species previously discussed, but it is also characteristic of estuarine situations (Wilson, 1932). It has a wide distribution from Cape Cod to the Texas Coast (Bowman, 1975) and may breed year-round, at least in Florida waters (Grice, 1960). It may be one of the species whose abundance is reduced when *Acartia tonsa* is abundant due to predation on *Oithona* larvae by adults of the calanoid (Lonsdale et. al. 1978).

F. *Euterpina acutifrons*

Although several other harpacticoids occur incidentally in the plankton, *Euterpina* is the only species usually considered to be pelagic (Lonsdale and Coull, 1977; D'Apolito and Stancyk, 1979) and it was the most abundant harpacticoid in the water column in this study. It was present at all times of year at NMF and SJ except January and

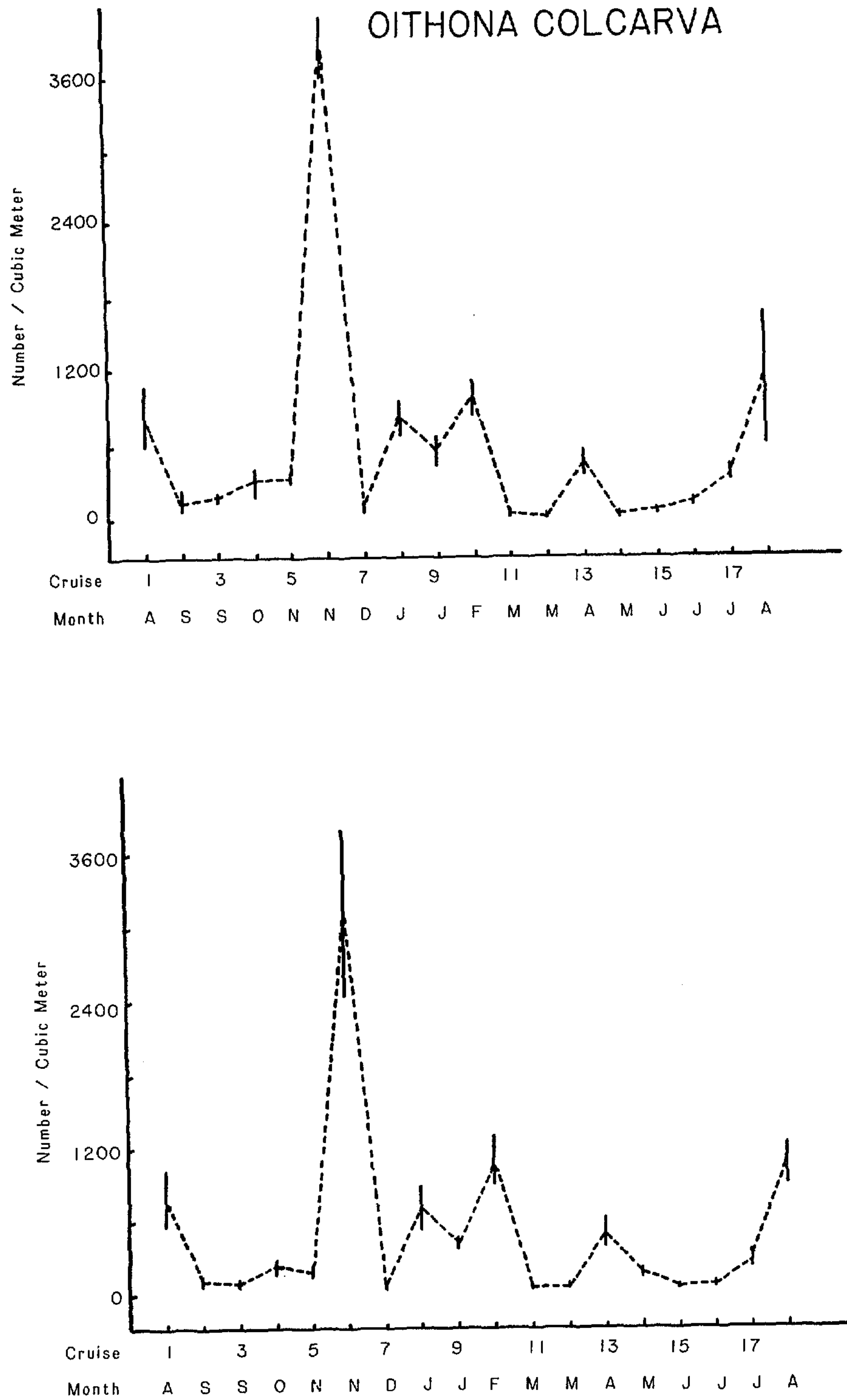


Figure 5-7. Mean densities (no./m^3) of *Oithona colcarva* on cruises 1 - 18 at NMF (above) and SJ (below). Vertical lines indicate plus or minus the standard error.

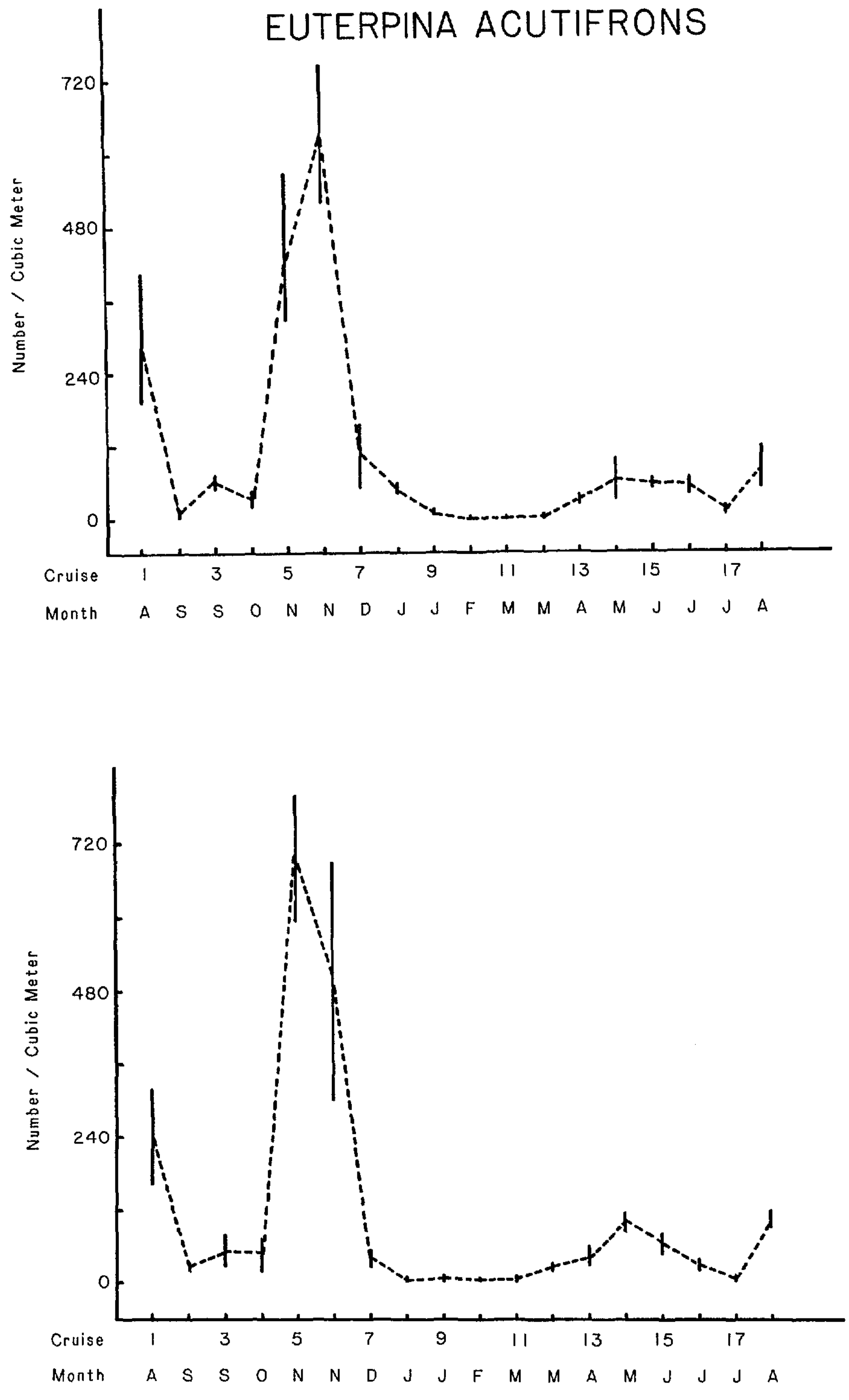


Figure 5-8. Mean densities (no./m^3) of *Euterpina acutifrons* on cruises 1 - 18 at NMF (above) and SJ (below). Vertical lines indicate plus or minus the standard error.

February (Fig. 5-8), with large peaks in both creeks in November. Abundances were generally similar between the two creeks. The year-round occurrence corresponds to findings in North Inlet by Lonsdale and Coull (1977), but they found peaks of abundance in the summer and early fall. D'Apolito and Stancyk (1979) found *E. acutifrons* in North Inlet only from April through December in 1977.

E. acutifrons has a worldwide distribution in coastal, shelf and estuarine waters (Fanta, 1972), and is known to breed only in the warmer times of year (at least 11^{o}C; optimal in North Inlet, 16.5^{o}C; D'Apolito and Stancyk, 1979). The species is unusual in that males are dimorphic and occur in the population simultaneously. Some authors (i.e., Moreira and Vernberg, 1968) have suggested that the two different types of males have different temperature-salinity tolerances, while others (Haq, 1973) have hypothesized that they breed with females in different frequencies or different times of year. In any case, the abundance of *Euterpina* in estuarine waters, together with its relatively small and delicate form (0.5 - 1.0 mm) make it prime food for larval fishes, and Kjelson et al. (1975) found it to be one of the dominant food items in the guts of menhaden (*Brevoortia tyrannus*), pinfish (*Lagodon rhomboides*) and spot (*Leiostomus xanthurus*) in the Newport River estuary, North Carolina.

G. Chaetognaths

Next to ctenophores, chaetognaths are probably the most voracious invertebrate predators of the zooplankton in the estuary. At NMF and SJ, their abundance was extremely seasonal (Fig. 5-9), with highest

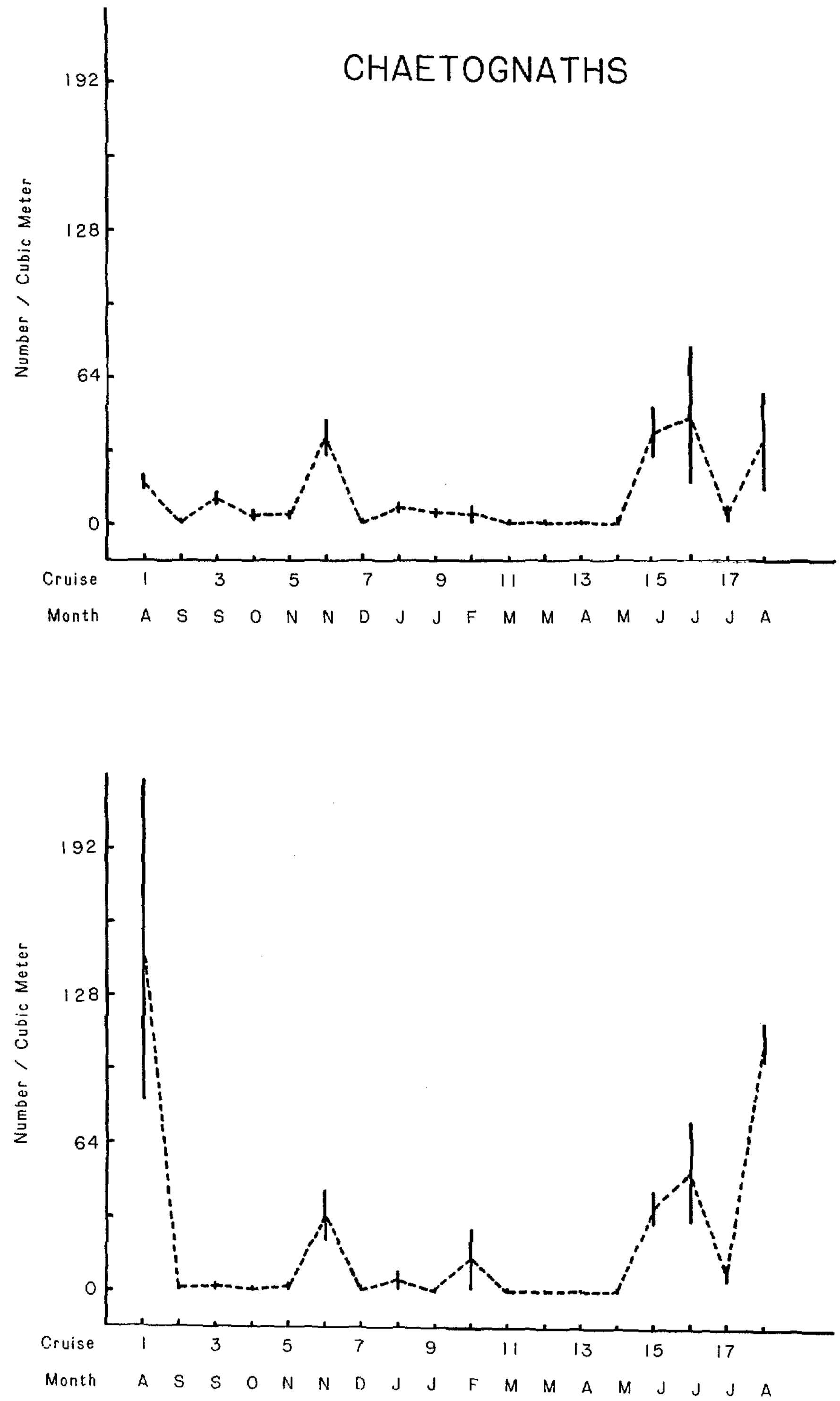


Figure 5-9. Mean densities (no./m^3) of chaetognaths in zooplankton collections on cruises 1 - 18 at NMF (above) and SJ (below). Vertical lines indicate plus or minus the standard error.

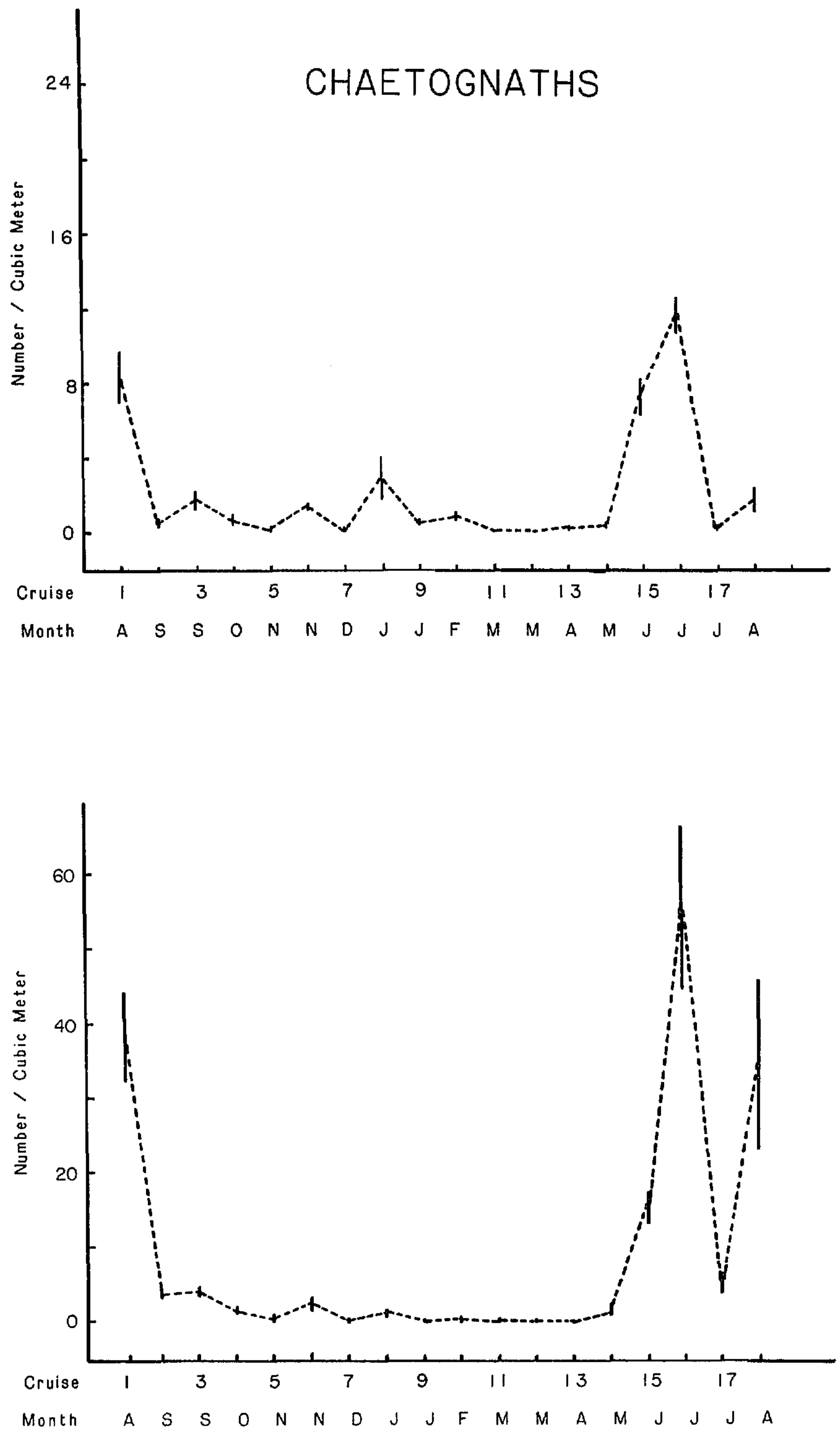
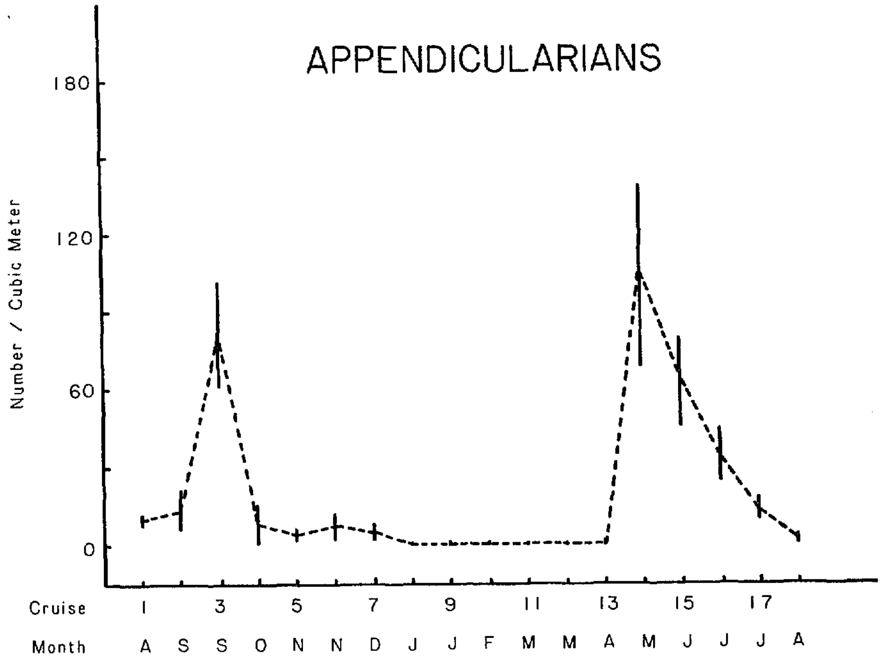


Figure 5-10. Mean densities (no./m^3) of chaetognaths in epibenthic sled collections on cruises 1 - 18 at NMF (above) and SJ (below). Vertical lines indicate plus or minus the standard error.

numbers in the summer, especially July and August. Numbers were similar between the two creeks, although chaetognaths were slightly more abundant at SJ in August of both 1980 and 1981. Since chaetognaths were captured in both zooplankton nets and the epibenthic sled, comparisons between the two methods of capture can be made. Figure 5-10 shows the numbers of chaetognaths captured in the sled, and the peaks of abundance correspond exactly with the zooplankton data (Fig. 5-9); however, estimates of numbers/m^3 are 2-3 times lower in the sleds. This could be because sleds capture chaetognaths less efficiently than nets, or because chaetognaths were actually more abundant in surface waters. Further sampling is being performed in Winyah Bay.

H. Appendicularians

These soft-bodied organisms, chiefly in the genus *Oikopleura*, are fairly common in nearshore coastal waters (Costello, 1981). They are much less abundant in estuaries, however, and occurred at NMF and SJ Creeks only sporadically (Fig. 5-11). They were most abundant in the spring and summer months, reaching densities up to 120/m^3. Such densities are low compared to counts as high as 20,000/m^3 made by Costello (1981) in nearshore South Carolina waters. Costello also found that appendicularians were generally swept into North Inlet, so the highest densities at any up-estuary station occurred at the highest tides. Inshore densities dropped precipitously, especially at low tide periods, so the small numbers of appendicularians found at NMF and SJ is not surprising. The unusual peak at NMF in September, 1980, and at South Jones in November, 1980, are probably due to significant input of coastal water masses at these times, and illustrate the way the occurrence of this species is closely tied to water flows.



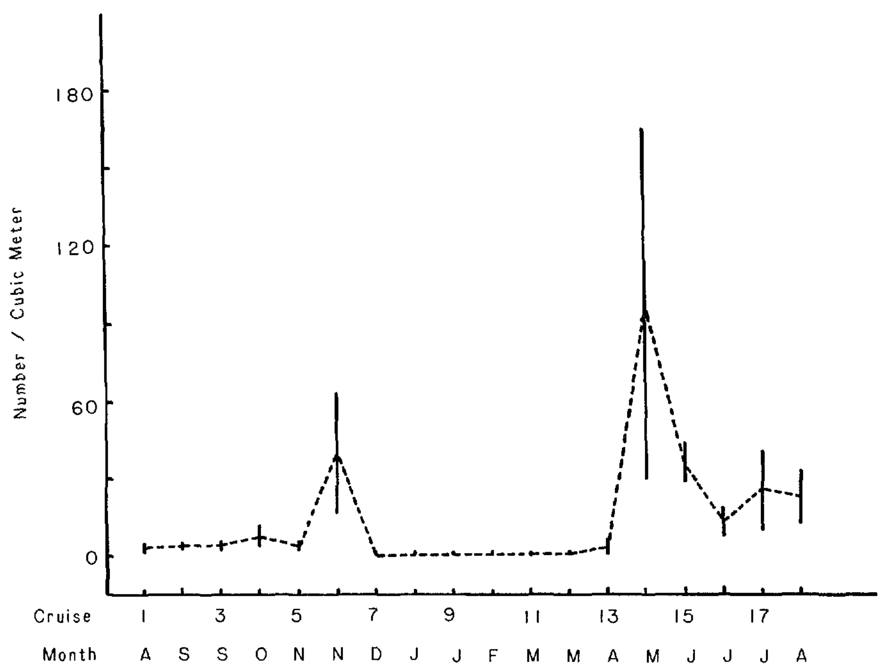


Figure 5-11. Mean densities (no./m^3) of appendicularians on cruises 1 - 18 at NMF (above) and SJ (below). Vertical lines indicate plus or minus the standard error.

Alldredge (1972, 1976) studied the importance of appendicularians and their houses in the Gulf Stream and Gulf of California. She cited numerous instances of calanoid and cyclopoid copepods, as well as several other forms of crustaceans, which rested on, rode in, or fed upon discarded mucus houses of appendicularians. Houses were built and discarded at a rapid rate (up to 6 times per day), and the rate was proportional to the amount of particulate material in the water. Since estuarine waters have high amounts of particulates, house production by the appendicularians in the Winyah Bay system is probably high. Thus, appendicularians may provide material for consumers not only as food items themselves, but also in the form of mucus houses which have often captured large amounts of phytoplankton, bacteria or fine detritus. Their role in the estuarine plankton may be masked by their low numbers, and studies by Stancyk and Ferrell (unpublished) indicate that these are the only adult zooplankton forms significantly imported into North Inlet. The role of mucus houses as a nutritional source, as well as a means of concentrating man-made or natural substances and passing them up the food chain, requires considerably more study (Alden, 1977).

II. MEROPLANKTON

The general meroplanktonic forms found in the Winyah Bay system and some aspects of their biology were discussed earlier in this chapter; the following section will deal only with the more abundant forms, and will emphasize specific sampling results at No Man's Friend and South Jones Creeks.

Barnacle nauplii were by far the most abundant larvae in the Winyah Bay zooplankton samples (Fig. 5-12), reaching peaks as high as 2100/m^3. They were present year round in both stations, with peak abundances in the fall (October) and spring. Peaks are especially clear at NMF, where between-peak densities were generally lower than at SJ. Abundance of barnacle nauplii at SJ was relatively high year round, averaging about 1200/m^3 versus about 600/m^3 for NMF. Barnacle nauplii are one of the few forms which show dramatic differences between the two creeks, and these could be due to many causes, including different numbers of adults in the two creeks to supply larvae to the overlying water column or more nauplii in nearshore coastal waters. In addition, there are almost certainly several species of barnacles producing larvae (Lang, 1979) which could lead to variations in barnacle nauplius numbers in both space and time due to variations in adult distribution. In any case, barnacle nauplii dominated the plankton from December through April, which is in marked contrast to North Inlet proper, where Lonsdale and Coull (1977) found highest densities of barnacle nauplii between April and August.

The more advanced stages of larval barnacles, the cyprids, were much rarer and more seasonal than the nauplii (Fig. 5-13). Densities of these forms were about an order of magnitude lower than the nauplii, and peaks occurred only during the months of January and June-July. There were only slight differences between the creeks, with SJ having slightly higher numbers, especially during peaks. As stated earlier, cyprid stages are the premetamorphosis forms, and the reduction of abundance could be due to more disjunct distributions, with cyprids generally occurring near the substrates (i.e., pilings, bottoms) on which they will ultimately

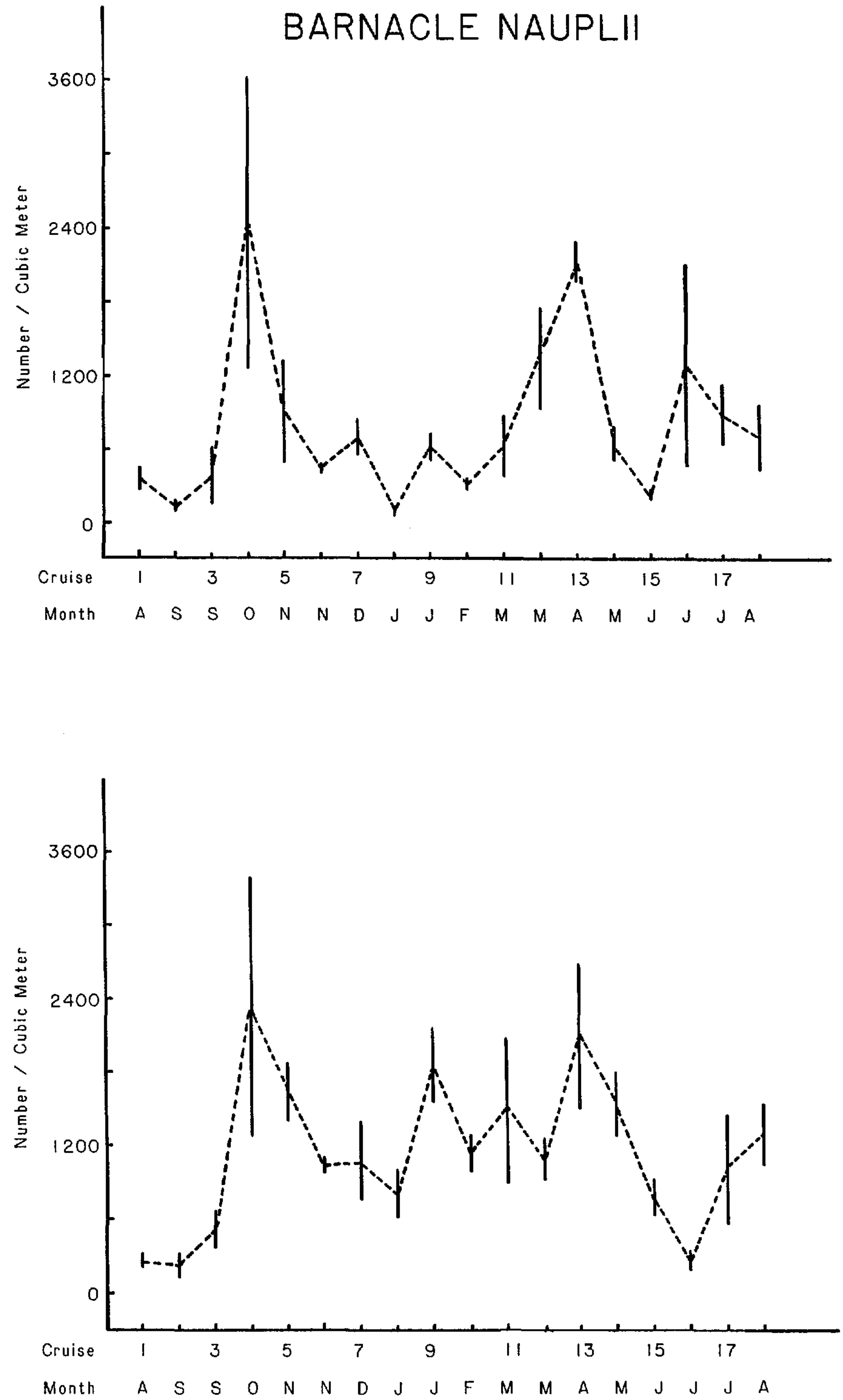


Figure 5-12. Mean densities (no./m^3) of barnacle nauplii on cruises 1 - 18 at NMF (above) and SJ (below). Vertical lines indicate plus or minus the standard error.

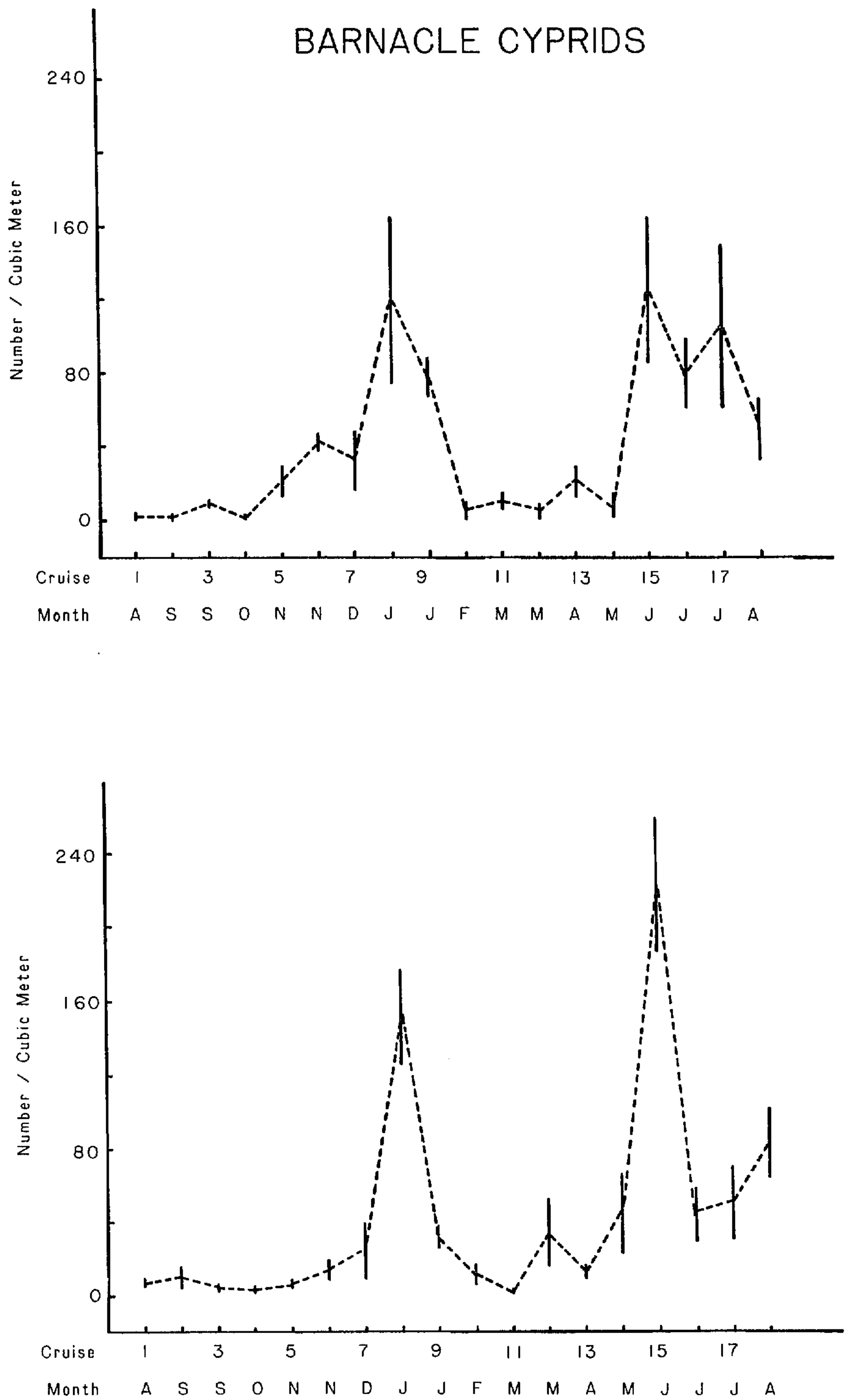


Figure 5-13. Mean densities (no./m^3) of barnacle cyprids on cruises 1 - 18 at NMF (above) and SJ (below). Vertical lines indicate plus or minus the standard error.

settle. Their larger size and greater weight would also tend to keep them near the bottom, where they would be less accessible to plankton nets. There is no obvious correlation between barnacle nauplius and cyprid abundance in either creek, although cyprid peaks tend to occur at times when nauplii are in lower abundance (Fig. 5-12 and 5-13).

Crab zoeae are extremely abundant in both creeks, but only at very specific times (Fig. 5-14). Previous studies have shown that the majority of the zoeae in the tidal creeks of North Inlet are *Uca spp.*, the larvae of fiddler crabs (DeCoursey, 1979; Christy and Stancyk, 1981). These larvae are all in the early stages of development (stages 1-3), and are released by their ovigerous female crabs at the time of highest nighttime spring tides during the spring and summer months (Bergin, 1981; Christy and Stancyk, 1981). The fact that crab zoeae show peaks only during one August and one June sample is due to sampling, and does not reflect annual zoeal production in these areas. Samples taken at times not within 3 days of maximum spring tides yield very few zoeae, because they have apparently been flushed from the system (Christy and Stancyk, 1981). Calculations performed on measurements of zoeal flux from North Inlet, for example, indicate that all zoeae entrained in the water passing back and forth across the inlet mouth would be exported within 7 tidal cycles. Earlier studies by Stancyk and Ferrell (unpublished) revealed that the response of zoeae to changes in direction of tide were much higher at SJ than at the mouth of North Inlet, indicating a greater tendency to be washed from the system in the southern creeks. The absence of zoeae in the non-spring tide summertime samples tends to reinforce these findings, and leads to the conclusion that while zoeal pro-

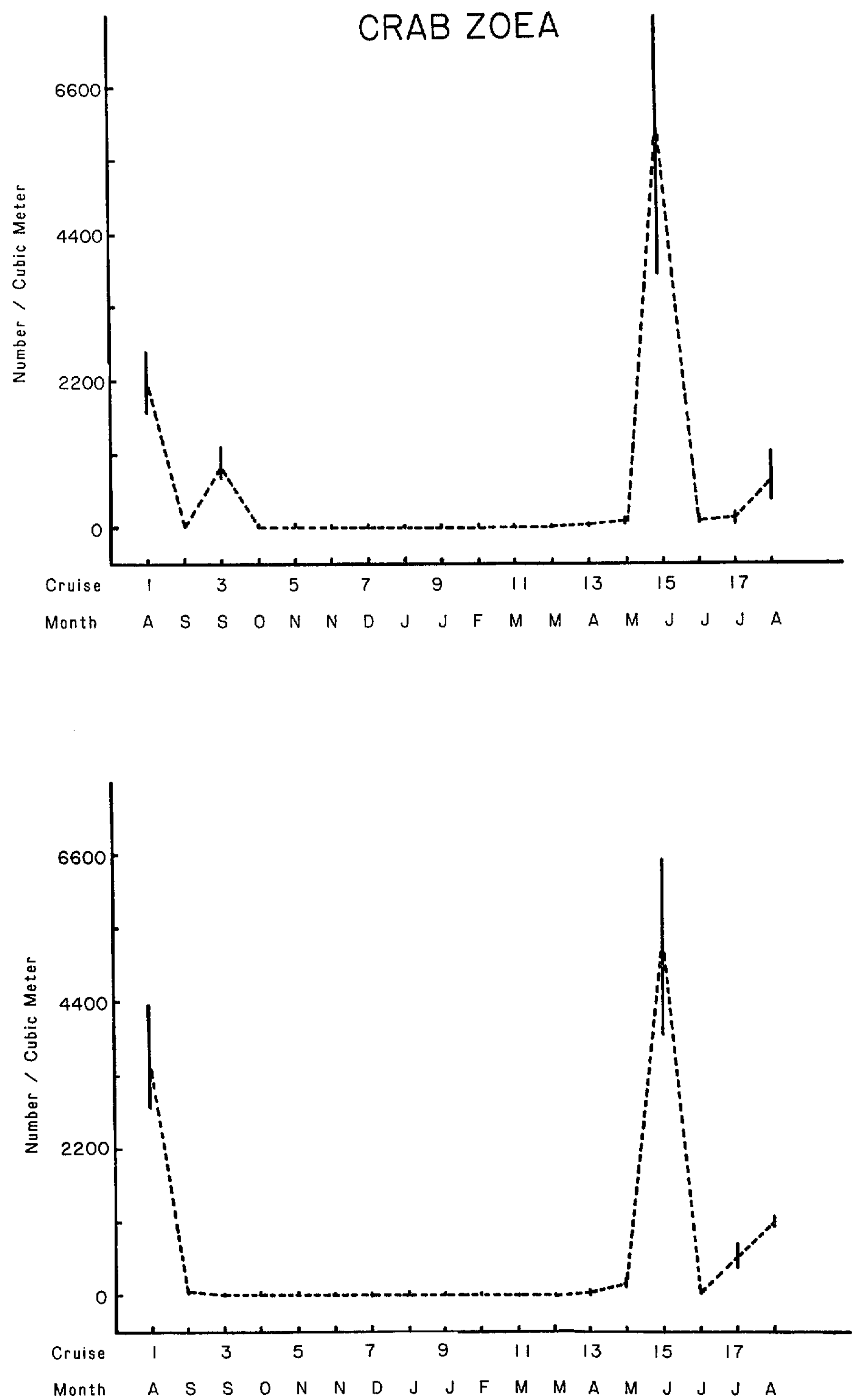


Figure 5-14. Mean densities (no./m^3) of crab zoeae on cruises 1 - 18 at NMF (above) and SJ (below). Vertical lines indicate plus or minus the standard error.

duction near nighttime spring tides may be quite high (over 5000/m^3) in southern creeks, zoeal export is sufficiently rapid to remove them quite quickly.

Finally, molluscan larvae showed distinct peaks of abundance at NMF and SJ Creeks. Bivalves (Fig. 5-15) had the strongest peak in early June, but also showed a distinct fall peak in late November. In both cases, numbers of bivalve larvae were small compared to most other forms, with 'peaks' of as few as 20 individuals/m^3. Gastropod larvae (Fig. 5-16) were more abundant, but also showed spring and fall peaks. The early June peak at South Jones was exceptional, and gastropod veligers dominated the samples at this time. This peak, which also occurs in several other forms (see Fig. 5-3,4,5,10,11,13, and 14), occurs on a nighttime spring tide when the water temperatures first approach 25^{o}C, and may mark a time of extremely high spawning activity among invertebrates in the system. There was a strong difference in abundance of veligers between SJ and NMF Creeks at this time, which could be due to differences in water masses or in the number of spawning adults in the two areas.

In summary, the zooplankton in South Jones and No Man's Friend Creeks is similar to that found in North Inlet (Lonsdale and Coull, 1977; Stancyk and Ferrell, unpublished) and other southeastern estuaries (Alden, 1977; Sandifer et al. 1980), but there are distinct differences in abundances and times of occurrence between areas. The most common species are generally widespread, but are more closely associated with warm waters than boreal, and are therefore thought to have affinities with Caribbean fauna (Sandifer et al. 1980). Numbers of species are relatively high, but diversity is limited due to the fact that most systems are dominated

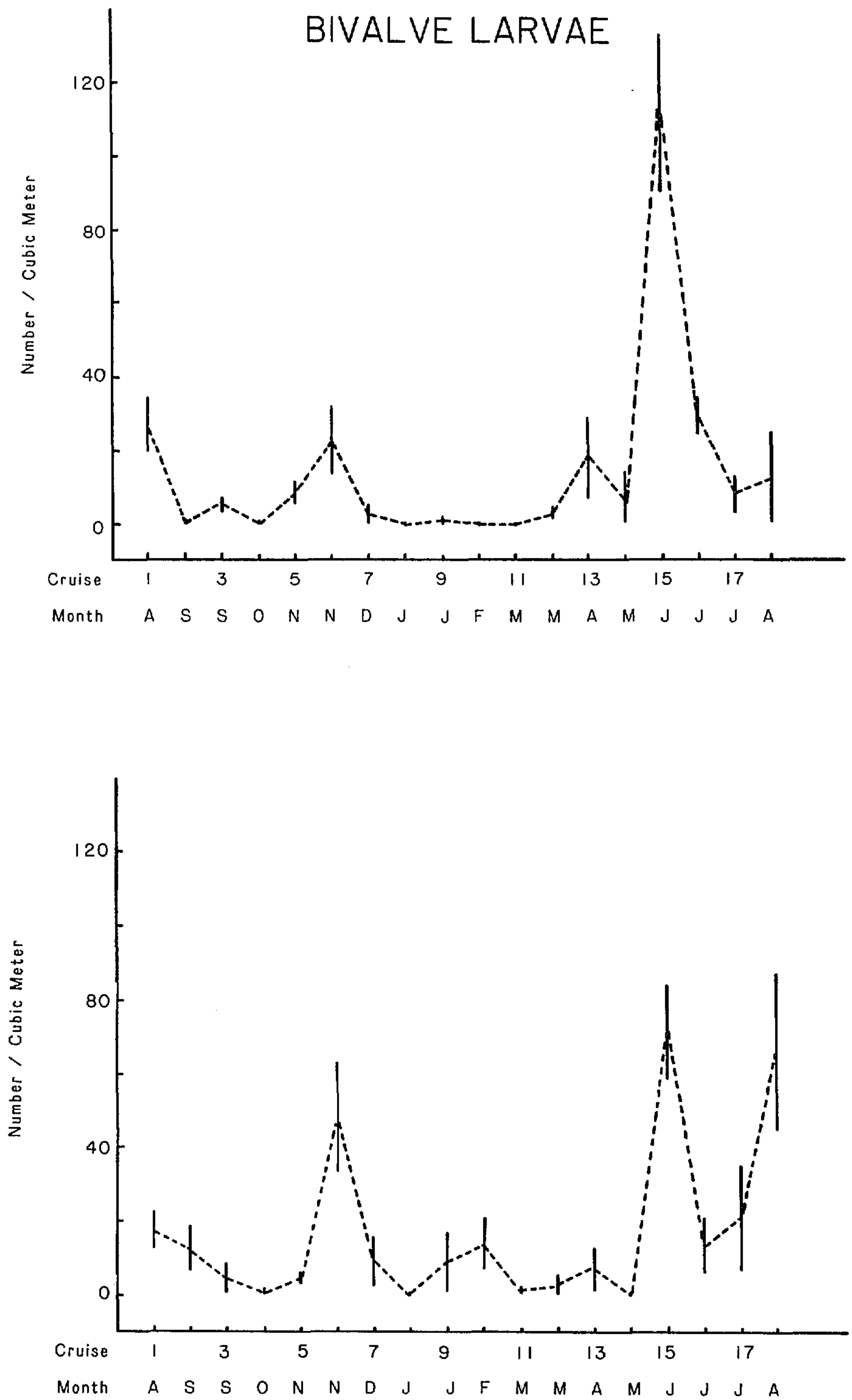


Figure 5-15. Mean densities (no./m^3) of bivalve larvae on cruises 1 - 18 at NMF (above) and SJ (below). Vertical lines indicate plus or minus the standard error.

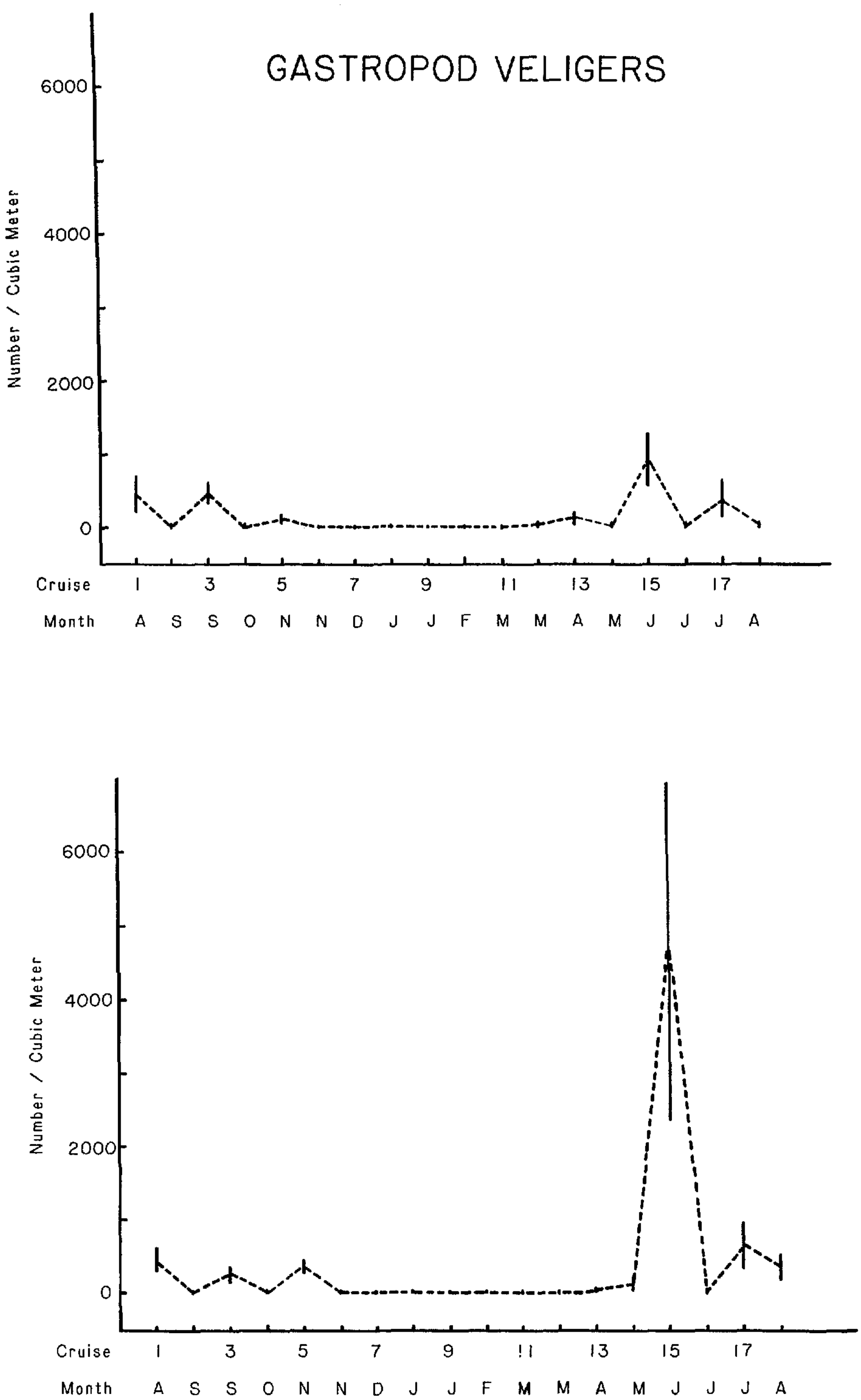


Figure 5-16. Mean densities (no./m^3) of gastropod veligers on cruises 1 - 18 at NMF (above) and SJ (below). Vertical lines indicate plus or minus the standard error.

by 4-7 categories or species. In general, production is higher in the spring and fall, with larval production occurring throughout the spring, summer and fall. Larval forms in the creeks can sometimes dominate the zooplankton and are usually common, but they are derived from a variety of adult forms whose distributions and numbers are not well-known. Many of the Winyah Bay zooplankton have been shown to provide food for other species, particularly larval fish and crustaceans (Thayer et al., 1974; Alden, 1977). Relatively few studies have been performed which shed light on the effect of human activities on zooplankton (see Chapter 10), but the general conclusions are that zooplankton communities (at least the copepods) can recover from perturbations like floating oil relatively quickly. Greater dangers come when negative impacts on the zooplankton result in toxic or harmful substances being passed up the food chain through the zooplankton, or in reduced recruitment into benthic invertebrate, crustacean or fish populations. Such phenomena usually occur slowly and are difficult to detect, but often have significant long-term impacts. In any case, the diversity and complexity of the zooplankton reinforces the concept that these organisms interact with, and have an impact on, many other parts of the estuarine-coastal ecosystem. Until more is learned about these connections and the role of the zooplankton, potential negative impacts on the community should be avoided.

CHAPTER 6. MOTILE EPIBENTHOS

The size, behavior, and microhabitats of subtidal estuarine organisms determine their susceptibility to collection in nets. Copepods and other weak-swimming zooplankton, less than 2 mm in length, are usually dispersed in the water column and are effectively sampled with plankton nets. Many other small (2-20 mm) invertebrates and larval fishes are undersampled by zooplankton nets because: (1) they are accomplished swimmers which can avoid slowly towed nets and (2) most have a strong affinity for the bottom. Such organisms are referred to as motile epibenthos. In the study of No Man's Friend (NMF) and South Jones (SJ) Creeks, a special type of sampling gear, an epibenthic sled, was used to determine the distribution and abundance of these organisms. The design and use of the sled were discussed in Chapter 2.

Motile epibenthic organisms may be either permanent ('holo') or temporary ('mero') members of the near bottom fauna. Permanent forms such as mysids, amphipods, and isopods usually occur within a few centimeters of the bottom, and, despite their abundance, they are rarely collected with bottom dredges, grabs, and trawls. Sampling devices other than sleds are equally ineffective in collecting late larval stages of decapod crustaceans and fishes which live near the bottom. Sometimes 'mero' forms totally dominate epibenthic sled collections.

The taxonomic composition and abundance of organisms in sled collections are highly variable. Swimming forms often aggregate and patchy distributions account for large differences in the abundance of certain species between consecutive sled tows. Some motile epibenthic species occur near the bottom only under certain environmental conditions (e.g., temperature, light, current velocity). Species closely associated with the substrate may be collected only over particular bottom types.

More than 700 epibenthic sled samples were collected, processed, and analyzed to provide information on the life history strategies and spatial and temporal distributions of motile epibenthic organisms at NMF and SJ. The results of the study are organized into nine sections, each describing the ecology of a major group of organisms. In the final section, trends in total organism abundance and distribution are discussed.

A. PERICARID CRUSTACEANS

The pericarids are a diverse group of small (generally less than 20 mm) shrimp-like and crab-like animals which raise their young in brood pouches rather than releasing larval stages into the water column. Most estuarine pericarids are 'holo' members of the near bottom fauna.

Mysid or opossum shrimp (Fig. 6-1a) are often the most abundant epibenthic crustaceans in shallow water sled collections. Of the 780 species of mysids known in the world (Mauchline, 1980), seven have been identified from the North Inlet and Winyah Bay area. *Neomysis americana* is by far the most abundant mysid in this region, and it is probably the most common shallow water mysid in the western North Atlantic Ocean (Wig-

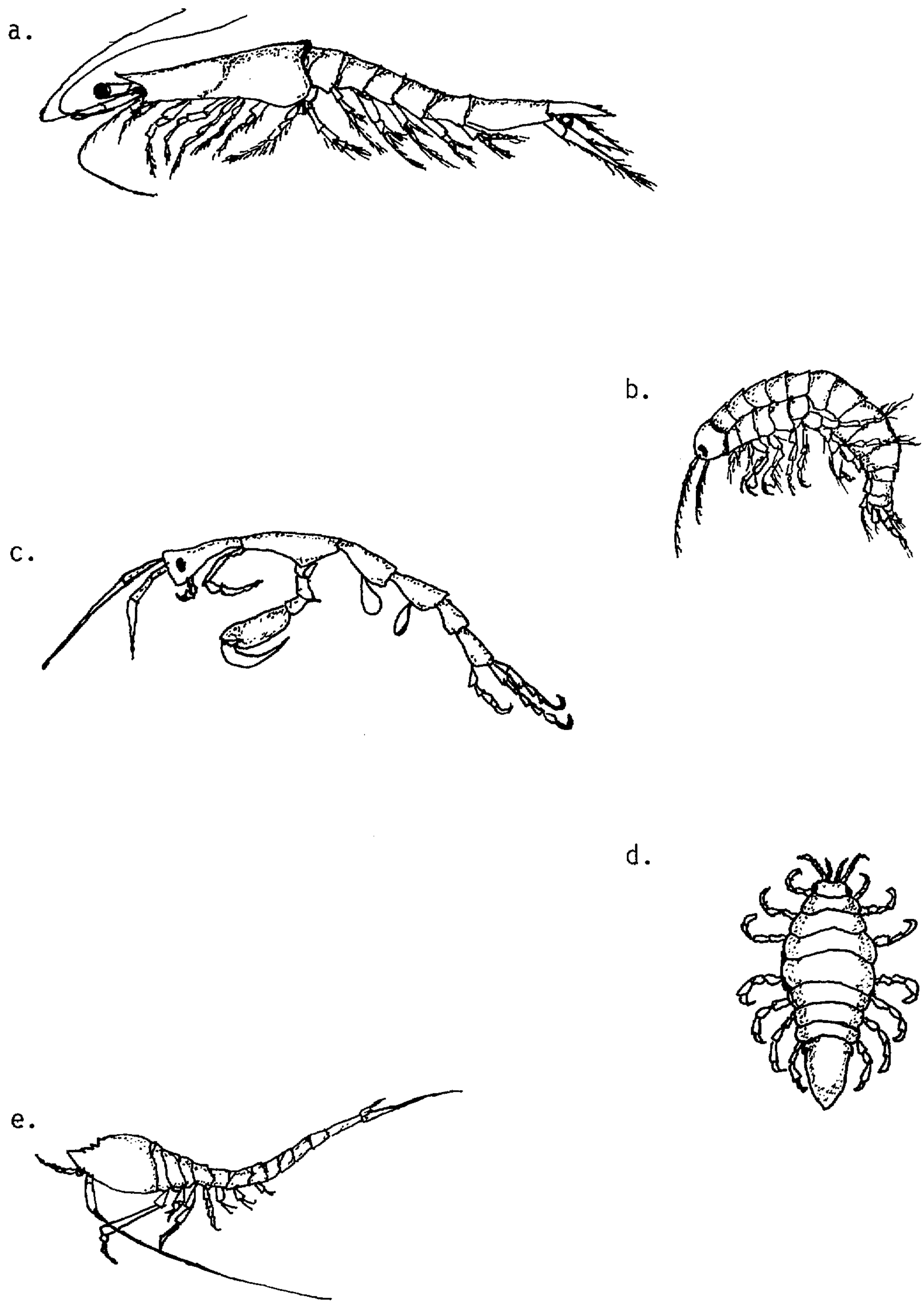


Figure 6-1. Pericaridan Crustaceans; generalized forms of a: a. mysid shrimp (10 mm); b. gammarid amphipod (5 mm); c. caprellid amphipod (6 mm); d. isopod (6 mm); e. cumacean (5 mm)

ley and Burns, 1971). Other mysids which have occurred in sled collections in the study area are: *Mysidopsis bigelowi, Mysidopsis bahia, Metamysidopsis swifti, Promysis atlantica, Brasilomysis castroi,* and *Heteromysis formosa* (Allen, unpublished).

Female mysid shrimps brood up to fifty young in a brood pouch located between their thoracic appendages. Young mysids which are released from the pouch resemble adults. Adult size is usually reached in two or three months; however, growth rates and longevities depend on environmental conditions. Mauchline (1980) described the life history pattern of many species of mysids. Details of the life cycle of *Neomysis americana* have been discussed by Herman (1962), Hopkins (1965), Allen (1978), and Pezzack and Corey (1979).

Mysids have a strong affinity for the bottom, and it is unusual to collect mysids high in the water column, especially during the day. Although the nocturnal vertical migration of mysids in coastal waters has been well documented (e.g., Herman, 1963), most mysids in tidal creeks remain near the bottom under all light conditions (Allen, unpublished). Mysids feed on concentrations of microscopic algae and organic particles near the bottom (Baldo-Kost and Knight, 1975), but also prey on zooplankton (Cooper and Goldman, 1980).

Mysids were consistently more abundant in SJ than NMF Creek (Fig. 6-2). On major cruises SJ densities were often at least twice as high. The seasonal pattern of abundance was similar at both creeks. *Neomysis americana*, which accounted for more than 95% of all mysids collected, occurred in very low numbers in summer. Densities increased in the fall

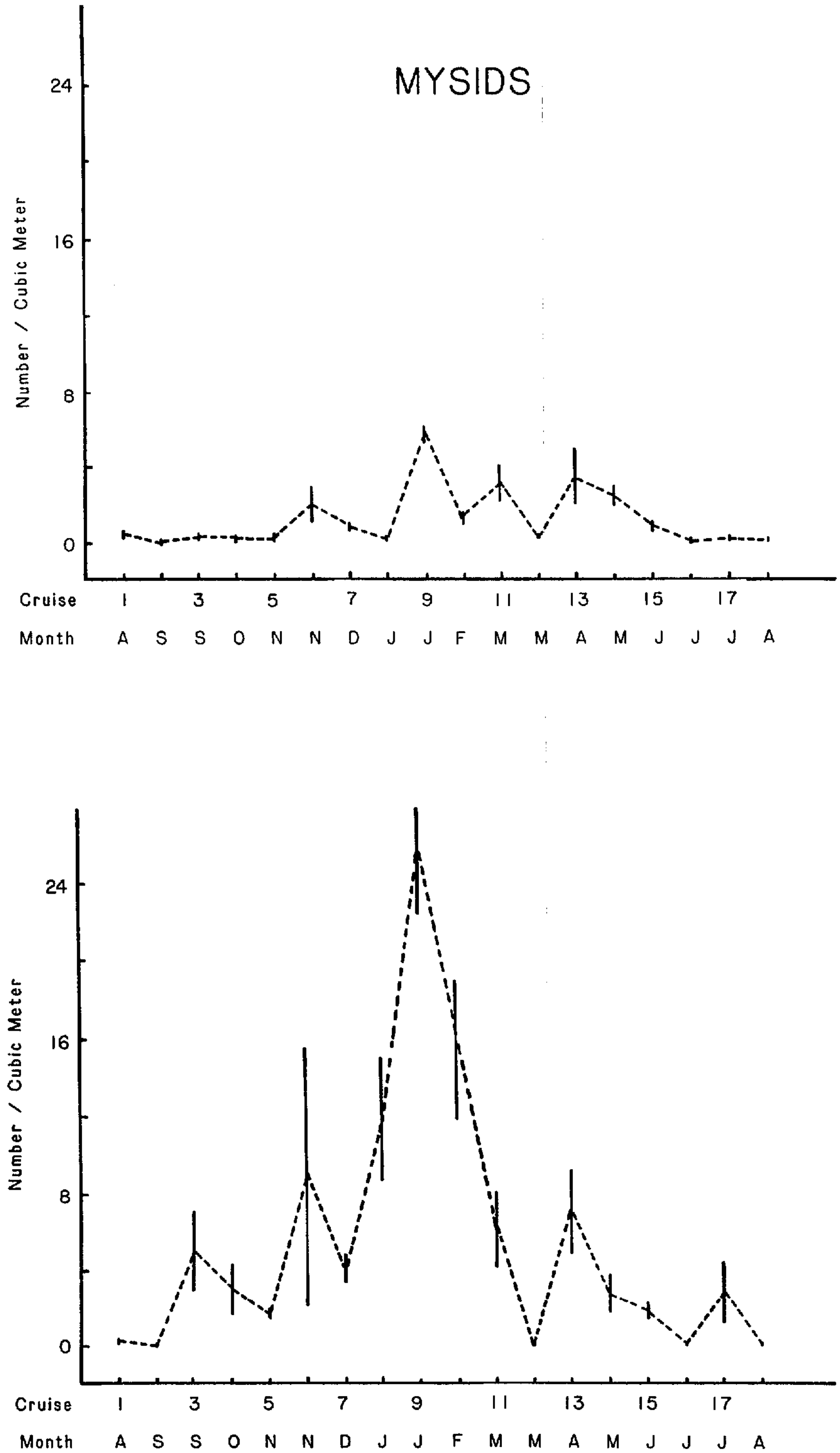


Figure 6-2. Mean densities (no./m^3) of mysid shrimps in epibenthic sled collections on cruises 1 - 18 at NMF (above) and SJ (below). Vertical lines indicate plus or minus the standard error.

to a winter peak, then decreased to low levels the following summer (Fig. 6-2 and Table 6-1). Winter sled collections in SJ often yielded thousands of adult mysids per tow.

The largest mysids of the year occurred from January through March. In early spring, large overwintering adults became reproductively active, brooded and released their young, then died. Young mysids dominated the population in April and May, but disappeared from collections shortly after the peak spring brood release. Predation by larval and juvenile fishes and the migration of mysids to other sections of the estuary may have accounted for the warm-water reductions in mysid densities. Large winter populations of *Neomysis americana* in the creeks probably resulted from migrations from adjacent coastal areas.

Although mysids are not as abundant in southern temperate and tropical estuaries as they are in marshes north of Cape Hatteras (Allen, unpublished), they play an important ecological role in local estuarine waters. Mysids are major sources of food for a variety of young estuarine fishes, particularly from fall through spring when larval decapod crustaceans and other 'mero' forms are not available.

Amphipods comprise another abundant group of pericarid crustaceans. Unlike mysids, which usually swim just above the bottom, amphipods typically remain close to sessile benthic organisms and bottom debris. Some species live in burrows or build tube-like shelters on the bottom. Because of their secretive habits, amphipods are generally not effectively sampled with an epibenthic sled. Amphipod distributions are patchy and the numbers collected may vary by a factor of 100 or more between conse-

Table 6-1. Percent composition of organisms in epibenthic sled collections on major cruises at No Man's Friend (NF) and South Jones (SJ) Creeks. Values (based on mean densities) represent the proportion of the total catch which each category comprises.

CRUISE NO.	1		3		5		7		9		11		13		15		17	
MONTH	AUG		SEP		NOV		DEC		JAN		MAR		APR		JUN		JUL	
CREEK	NF	SJ	NF	SJ	NF	SJ	NF	SJ	NF	SJ	NF	SJ	NF	SJ	NF	SJ	NF	SJ
Mysids	1	<1	4	27	15	34	42	80	64	87	74	72	66	83	2	2	1	20
Amphipods	2	<1	2	<1	6	12	7	3	9	5	1	3	2	2	<1	1	5	10
Cumaceans	<1	<1	3	3	6	1	16	3	1	2	<1	1	<1	<1	<1	<1	5	1
Isopods	1	<1	1	1	<1	1	1	1	<1	<1	1	1	0	<1	<1	<1	<1	3
Shrimp Larvae	17	7	15	9	4	5	<1	<1	<1	0	1	<1	<1	2	7	2	15	30
Other Dec. Shrimp	11	15	2	6	16	15	3	3	4	2	6	8	9	1	2	10	6	0
Crab Megalopae	18	13	40	31	25	13	5	2	0	0	0	0	<1	<1	33	58	2	<1
Chaetognaths	46	60	32	21	20	15	16	4	15	<1	2	<1	9	<1	44	13	8	28
Fish Larvae	2	3	1	2	8	3	8	3	4	2	14	13	8	3	10	13	48	7
Others	2	1	<1	<1	<1	1	2	1	3	1	1	2	5	8	1	1	10	<1

cutive tows. Highest densities occur when the sled disrupts large sponges or oyster shell clusters which shelter local concentrations of amphipods.

The taxonomy or scientific classification of amphipods is notoriously difficult. Two suborders account for the majority of species in coastal South Carolina waters. Suborder Gammaridea is represented by more than 250 species, and at least 11 species from the suborder Caprellidae have been recorded in state waters (Fox, 1978). It was beyond the scope of this project to identify all species collected; however, gammarids (Fig. 6-1b) of the genera *Melita, Monoculodes, Batea,* and *Gammarus* and caprellids (Fig. 6-1c) of the genus *Caprella* were most common. Major taxonomic references for the amphipods of this region are: Barnard (1969), Bousfield (1973), and Fox and Bynum (1975).

The life history patterns of gammarid and caprellid amphipods are similar to those of mysids. Young are brooded in a marsupium and released as miniature adults. Aspects of the reproductive ecology of some gammarids have been studied by Van Dolah (1978), Borowsky (1980), Van Dolah and Bird (1980), and Hastings (1981). Population structures of caprellids have been reported by Caine (1979).

Gammarid amphipods were collected on every cruise, but densities were usually less than $2/m^3$ in sled collections at NMF and SJ (Table 6-2). Densities were generally higher at SJ. No pattern in the fluctuation of abundance between cruises was apparent.

Caprellid amphipods were always less abundant than gammarids (Table 6-2). There was a strong correlation between the abundance of caprellids and the volume of hydrozoans and bryozoans in sled collections which is

Table 6-2. Mean densities of pericarid crustaceans expressed as the number of organisms per cubic meter of water filtered. Abbreviations are NF = No Man's Friend Creek, SJ = South Jones Creek.

		GAMMARIDS		CAPRELLIDS		CUMACEANS		ISOPODS	
CRUISE	MONTH	NF	SJ	NF	SJ	NF	SJ	NF	SJ
1	AUG	1.0	0.5	0.2	<0.1	0.1	<0.1	0.3	0.3
3	SEP	0.3	0.2	0.2	0.1	0.4	0.6	0.2	0.2
5	NOV	0.2	0.6	0	0.1	0.2	0.1	<0.1	0.1
7	DEC	0.1	0.1	<0.1	<0.1	0.3	0.2	<0.1	<0.1
9	JAN	0.8	1.3	<0.1	0.1	0.1	0.7	<0.1	0.1
11	MAR	<0.1	0.2	0	<0.1	<0.1	0.1	<0.1	0.1
13	APR	0.1	0.2	0	0	<0.1	<0.1	0	<0.1
15	JUN	0.2	0.6	<0.1	0.2	0.2	0.3	<0.1	0.3
17	JUL	0.5	1.2	0.1	0.2	0.5	0.2	<0.1	0.4

not surprising since they normally live in association with colonies of soft bodied sessile invertebrates. Caprellids were collected in very low densities from fall through spring and none were taken at either station in April. Together, gammarid and caprellid amphipods usually accounted for less than 5% of the total catch (Table 6-1).

Cumaceans (Fig. 6-1e) represent a third major group of pericarid crustaceans. These little known animals tend to spend much of the time buried in the sediment. Benthic sampling devices such as corers and grabs have been used to collect cumaceans from estuarine and deep ocean bottoms. The epibenthic sled is designed not to disturb the sand and mud creek bottoms, yet some cumaceans were collected on every major cruise. Densities were usually less than $1/m^3$ and no regular pattern of abundance was observed between stations or cruises (Table 6-2). With the exception of the December NMF collections, cumaceans were minor constituents of the total catch (Table 6-1).

Leucon americanus, the most commonly collected cumacean, occurred at both stations on all cruises. *Cyclaspis varians*, *Oxyurostylis smithi*, and at least two unidentified species were also collected at NMF and SJ. Useful taxonomic references for the cumaceans of this area are Watling (1979) and Zimmer (1980).

Isopods (Fig. 6-1d) constituted the fourth major group of pericarid crustaceans collected in the sled study. These small (generally less than 15 mm) dorsoventrally flattened crustaceans occur in estuarine waters throughout the year. Some species remain buried in the sediment, while others are associated with sponges and macrodetritus. Many are parasites of fishes. More than 70 species are known from South Carolina waters (Kelley, 1978).

The weak swimming species *Edotea montosa* was the most commonly collected isopod at NMF and SJ. *Aegathoa oculata,* a strong swimmer, was also collected on most cruises. *Cassidinidea lunifrons*, at least one species of *Chiridotea*, and several unidentified species were taken less frequently. Menzies and Frankenberg (1966) provide descriptions of most local isopods.

Isopods were always most abundant at SJ; however, the densities at both creeks were generally less than $1/m^3$ (Table 6-2). Some isopods were collected on every major cruise except April at NMF, but they were most abundant in summer collections.

B. DECAPOD CRUSTACEANS

Most familiar crustaceans including the commercial shrimps, crabs, and lobsters belong to the Order Decapoda. More than 270 species of decapods occur in the marine waters of South Carolina (Young, 1978), and approximately 50 species of shrimps and crabs have been collected at NMF and SJ (Allen, unpublished). At least 12 species of decapod shrimps were collected with the epibenthic sled.

Two species of sergestid shrimps, *Lucifer faxoni* (Fig. 6-3b), and *Acetes americanus* (Fig. 6-3c), were collected in sled and zooplankton tows only during the warmest months (Table 6-3). These small shrimps are regarded as members of the coastal plankton, but they are regularly collected in high salinity regions of North Inlet and Winyah Bay. Al-

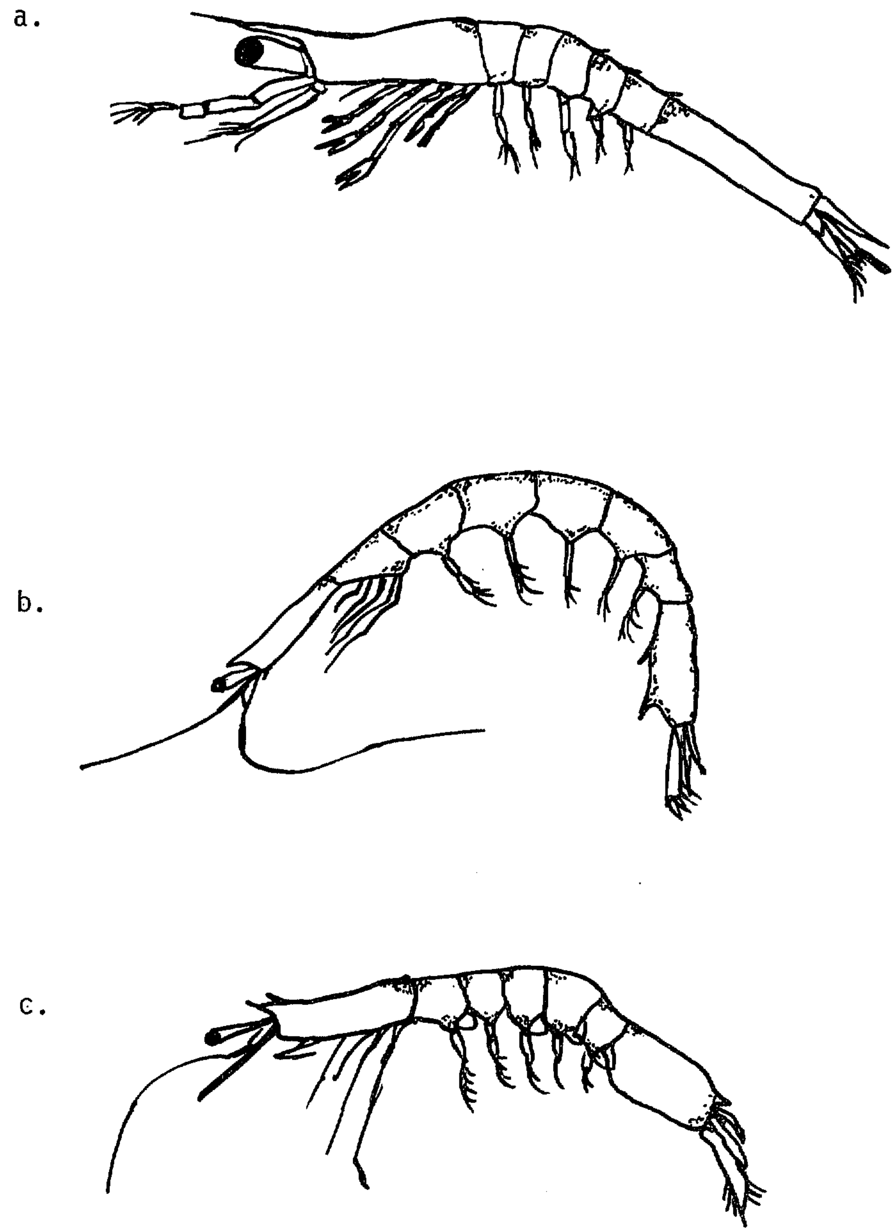


Figure 6-3. Decapod Crustaceans: a. postlarva of penaeid shrimp (7 mm); b. *Lucifer faxoni*, adult sergestid shrimp (10 mm); c. *Acetes americanus*, adult sergestid shrimp (10 mm)

Table 6-3. Mean densities of juvenile (including postlarval) shrimps, *Lucifer faxoni* and *Acetes americanus*, expressed as number of organisms per cubic meter of water filtered.

		JUVENILE SHRIMP		*Lucifer faxoni*		*Acetes americanus*	
CRUISE	MONTH	NF	SJ	NF	SJ	NF	SJ
1	AUG	0.3	0.2	3.6	4.4	1.0	5.1
3	SEP	0.1	<0.1	<0.1	0.1	<0.1	0.4
5	NOV	0.3	0.7	0.1	0.1	0	0
7	DEC	0.1	0.2	0	0	0	0
9	JAN	0.3	0.6	0	0	0	0
11	MAR	0.3	0.7	0	0	0	0
13	APR	0.4	0.1	0	0	0	0
15	JUN	0.4	11.2	0.2	0.1	0.1	0.3
17	JUL	0.5	0.7	0.1	<0.1	0.1	0.2

though *Lucifer* and *Acetes* are more effective swimmers than most zooplankton, their occurrence in estuaries probably is related more to their passive transport with penetrating coastal water masses than to active migration. Densities of both shrimps were generally higher at SJ than at NMF (Table 6-3).

Acetes was generally more abundant than *Lucifer* in the sled samples (Table 6-3). Williams (1965) provides some information on the distribution of *Acetes* in North Carolina estuaries; however, little is known about the life history and ecology of this shrimp. Maximum size for *Acetes* is about 26 mm (Williams, 1965).

Early workers (e.g., Brooks, 1882) believed that *Lucifer* was a primarily estuarine species, but recent studies suggest that it is widely distributed in the Atlantic and Pacific Oceans to a depth of 100 m (Williams, 1965). Bowman and McCain (1967) studied the distribution of this shrimp in the western North Atlantic.

Small shrimps (25 mm) of the genera *Periclimenes, Latreutes,* and *Neopontonides* were frequently collected in sled samples which contained excessive amounts of sponges and soft corals. These decapods live near the bottom in shallow marsh waterways and are usually associated with sessile benthic communities. *Lysmata* and *Ogyrides* were also collected in sled tows at NMF and SJ Creeks. None of these small decapod shrimps was collected with enough regularity or in sufficient numbers to determine its spatial or temporal distribution. In general, little is known about the life cycles and ecology of these small shrimps.

Palaemonetes pugio is by far the most common small decapod shrimp in temperate marsh waterways. Two other species of *Palaemonetes* also occur in the study area (Young, 1978), but are much less abundant. Microscopic examination is necessary to distinguish the three species. Grass shrimp are typically found along marsh creek banks and in pools on the marsh surface. They are excellent swimmers, but spend much of their adult lives walking and feeding on detritus laden bottoms and obstructions. Few adults are collected in sandy areas or swimming in the water column. It is unlikely that any other decapod shrimp is as abundant in the study area as *Palaemonetes*. Densities of thousands per cubic meter have been recorded in North Inlet creeks (Allen, unpublished).

Female decapod shrimps carry eggs on abdominal pleopods and eventually release small (<1 mm) larvae which remain in the water column as zooplankters until they grow to several millimeters in length and develop a stronger affinity for the bottom. The identification of decapod shrimp larvae is very difficult and no attempt to determine the taxonomic composition of the sled catch was made. Fig. 6-4 shows the distribution of all shrimp larvae retained by the 365μm mesh sled net. A distinct seasonal trend was apparent and consistent with other observations on the occurrence of gravid female shrimp. Densities at both creeks were greatest during the warm months and lowest from October to April. The decrease in abundance of shrimp larvae in July and August may indicate that peak spawning may occur in early summer and again in early fall, but only preliminary evidence for a bimodal pattern is available at this time. Larvae were somewhat more abundant at NMF (Fig. 6-4).

In the analysis of the sled collections, all decapod shrimps which had developed beyond the planktonic larval stages were regarded as juve-

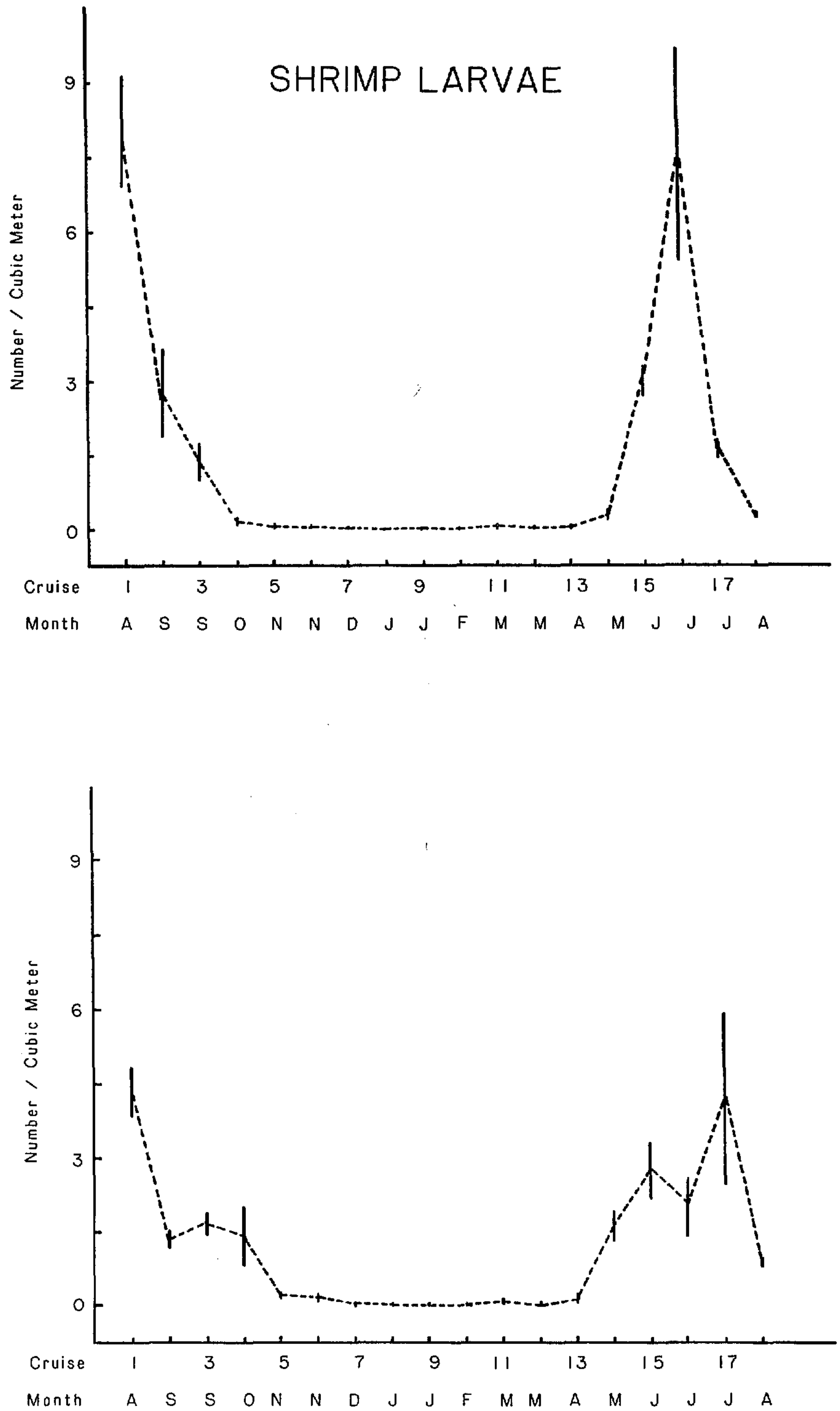


Figure 6-4. Mean densities (no./m^3) of shrimp larvae in epibenthic sled collections on cruises 1 - 18 at NMF (above) and SJ (below). Vertical lines indicate plus or minus the standard error.

niles. These forms were usually greater than 4 mm in length and often had developed enough of the adult characteristics so that they could be identified as palaemonid, penaeid, or other shrimps. The abundance of juvenile shrimps was usually less than $1/m^3$, but high densities of post-larval and juvenile penaeids were collected at SJ in June (Table 6-3). Although some penaeids were collected in July, most juvenile shrimp in sled collections were palaemonids. Some juvenile shrimp were collected each month.

The abundance of all shrimps (larvae, juvenile, and adults) collected with the epibenthic sled is shown in Fig. 6-5. The seasonal pattern, with maximum densities in summer and minimum densities in winter, was similar to that observed for the larvae, but total shrimp densities were significantly higher than larvae densities from December to June (Fig. 6-4 and 6-5), especially at SJ. This difference was due to the occurrence of adult grass shrimp (*Palaemonetes*) on the creek bottoms. During the cold months, grass shrimp move from the edges of the creeks to the deeper channels. Aggregations on the channel bottoms were frequently so large when water temperatures were below $10^{\circ}C$ that tens of thousands of 10-20 mm adults were taken in otter trawl collections. Grass shrimp adults were much more abundant at SJ. Even though adult grass shrimp were collected in practically every sled tow during the winter, none occurred from spring to fall.

The largest shrimps which occur in South Carolina estuaries are the penaeids. White shrimps (*Peneaus setiferus*), brown shrimps (*P. aztecus*), pink shrimps (*P. duorarum*), and spotted shrimps (*Trachypeneaus constrictus*) were collected at both creeks. The results of the trawl study on

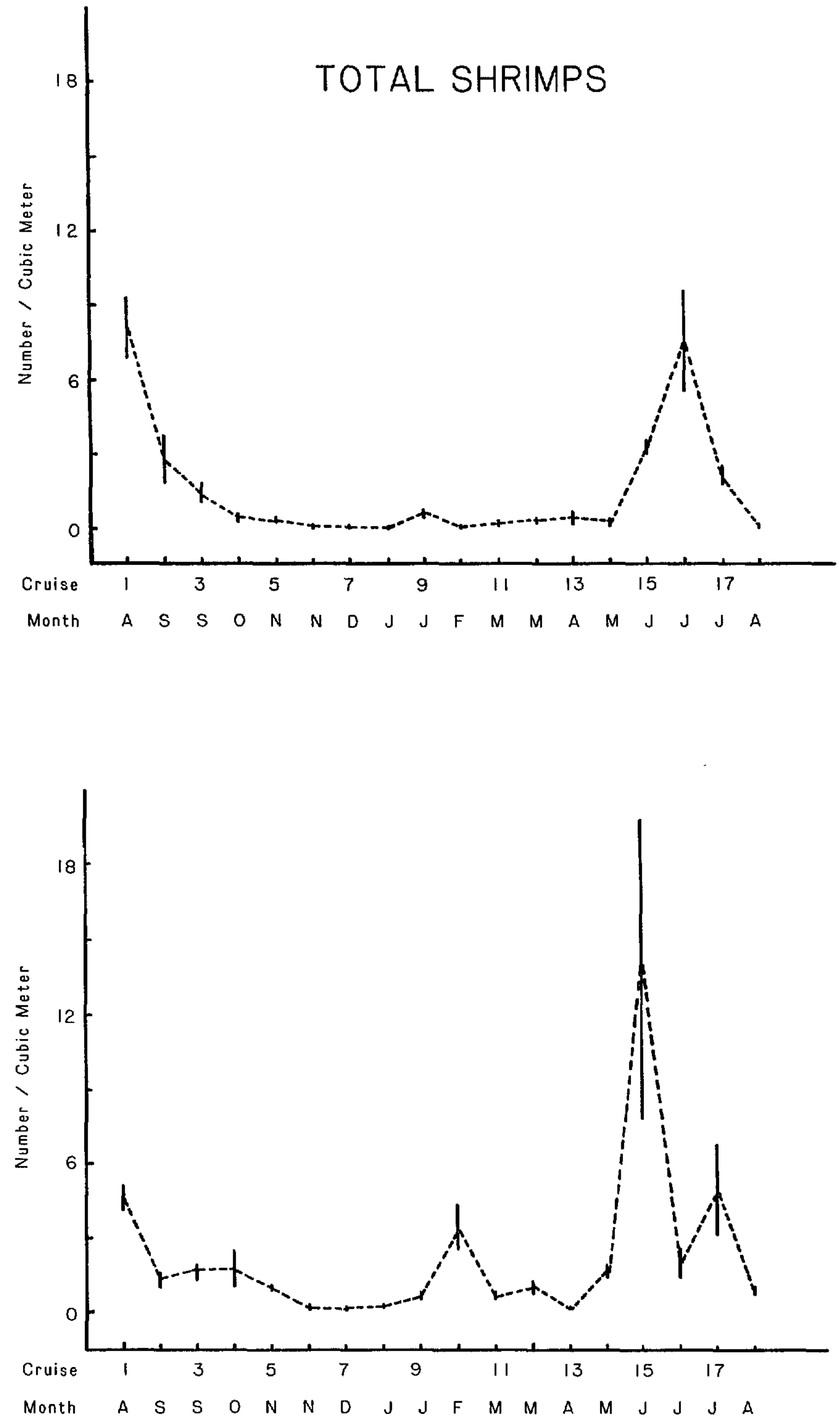


Figure 6-5. Mean densities (no./m^3) of total shrimps in epibenthic sled collections on cruises 1 - 18 at NMF (above) and SJ (below). Vertical lines indicate plus or minus the standard error.

the distribution and abundance of the commercial shrimps at NMF and SJ are discussed in Chapter 7, so only comments pertinent to the occurrence of early life stages in sled collections are presented here.

Adult penaeid shrimps release demersal eggs in the ocean and several planktonic stages are passed before postlarval shrimps (Fig. 6-3a) migrate into estuarine nursery grounds (Linder and Anderson, 1956). After a period of rapid growth, penaeid shrimps return to the ocean. Postlarval and small juvenile penaeid shrimps were taken in sled collections at NMF and SJ. Additional information on the occurrence of young penaeids in the study area is given in Chapter 7.

Other decapod shrimps represented in sled samples included various life stages of cryptic burrowing species such as *Upogebia*, *Callianassa*, and *Alpheus*. Adults of these common decapod crustaceans were not collected with the sled; however, late larval stages were common in sled samples from both creeks during the summer.

At least 187 species of anomuran and brachyuran crabs are known from coastal South Carolina (Young, 1978), and, although many are habitat specific and live in ocean waters far from shore, the majority live in shallow areas. Relatively few are truly estuarine organisms, but the abundance and ecological significance of a few inshore species is immense.

The most familiar of the anomurans are hermit crabs. Adult hermit crabs of the genera *Clibanarius* and *Pagurus* walk on the creek bottoms. Only small hermit crabs which had recently settled from their planktonic larval stages were captured with regularity. Densities of shell-less hermit crabs were never greater than $1/m^3$, and they occurred at both creeks during the summer cruises.

The familiar walking and swimming crabs are brachyurans. Few adult brachyurans were collected with the sled, but juvenile *Libinia, Cancer, Eurypanopeus, Menippe, Panopeus, Pilumnus, Pinnixa* and *Pinnotheres* were taken. Swimming crabs of the genera *Portunus, Callinectes,* and *Ovalipes* were generally more common than other types.

The life cycle of decapod crabs includes several planktonic larval stages. The common blue crab, *Callinectes sapidus,* has a life history pattern which is only slightly different from other estuarine brachyurans. Female crabs mate in brackish water from February to November and produce an egg mass which contains up to two million eggs. Eggs hatch in about two weeks and the zoea larvae which emerge are only a fraction of a millimeter in size. Zoeae molt six or more times during the next several weeks, but they remain planktonic forms until they molt into megalops larvae (Fig. 6-6a). A first crab stage emerges from the megalops' and at this stage, the animal finally resembles the adult.

Since many zoeal stages of brachyurans are too small to be retained by the mesh of the sled net, zoeae were not enumerated in the sled sample analyses. Densities of crab zoeae in zooplankton collections at NMF and SJ were reported in Chapter 5. Megalopae were retained by both the zooplankton and sled meshes and the densities of these larvae determined with the two gear types are presented in Figures 6-7 and 6-8. The same general pattern of seasonal abundance was observed for both gear types at both creeks. Megalopae densities decreased from fall to nearly zero during the cold months, then increased sharply in May and June. Densi-

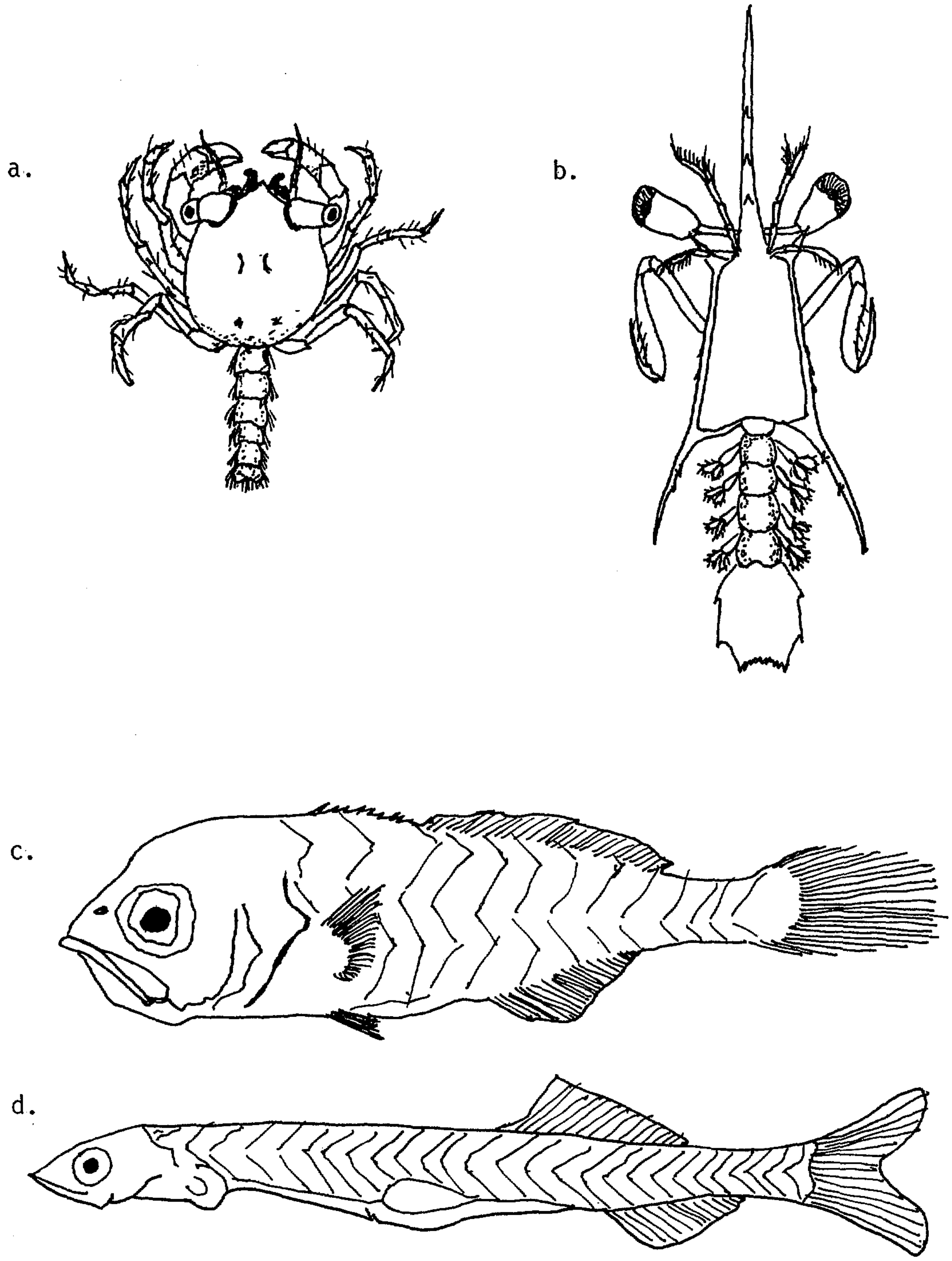


Figure 6-6. a. crab megalops (4 mm); b. stomatopod larva (10 mm); c. sciaenid fish larva (5 mm); d. anchovy larva (6 mm)

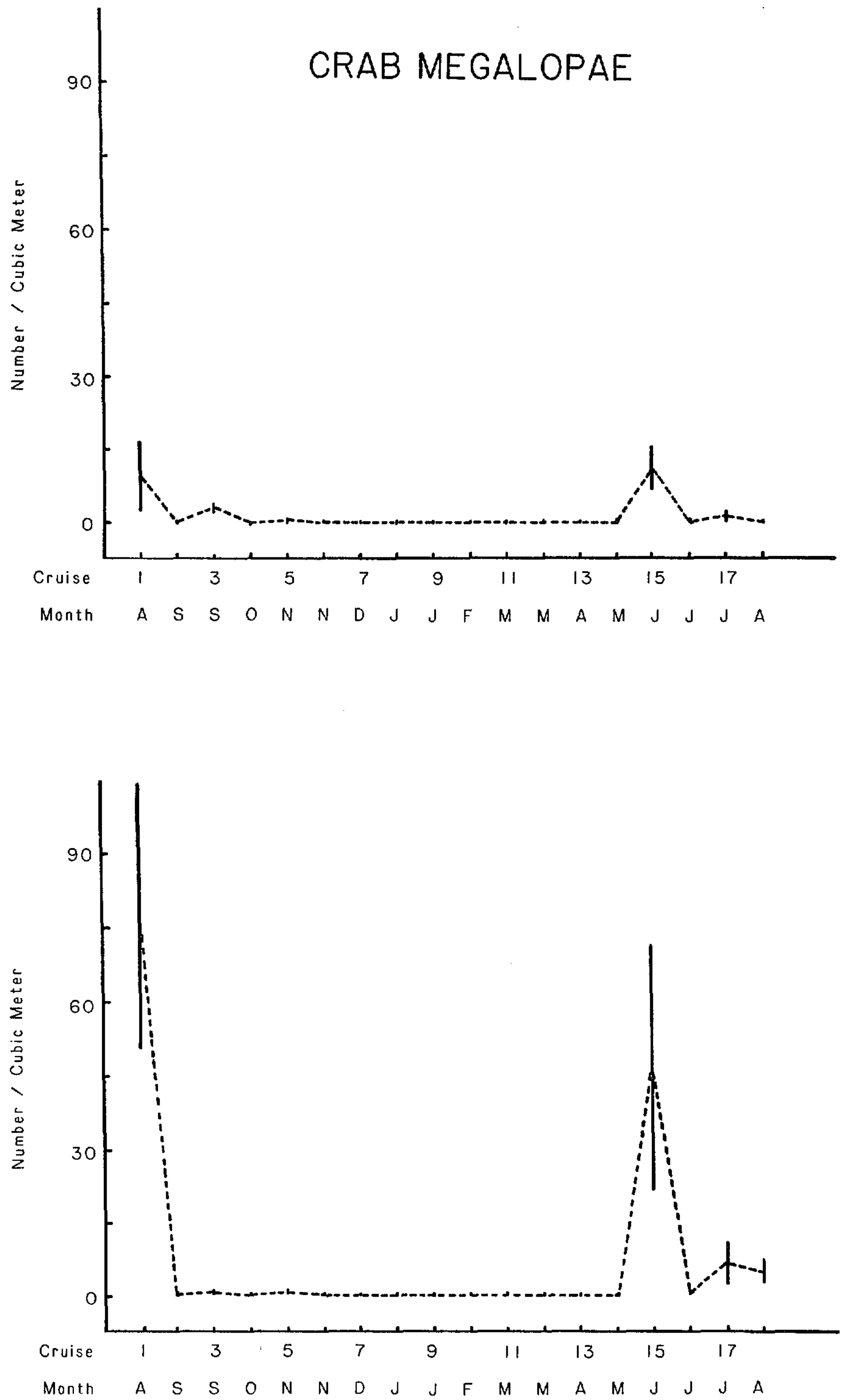


Figure 6-7. Mean densities (no./m^3) of crab megalopae in zooplankton collections on cruises 1 - 18 at NMF (above) and SJ (below). Vertical lines indicate plus or minus the standard error.

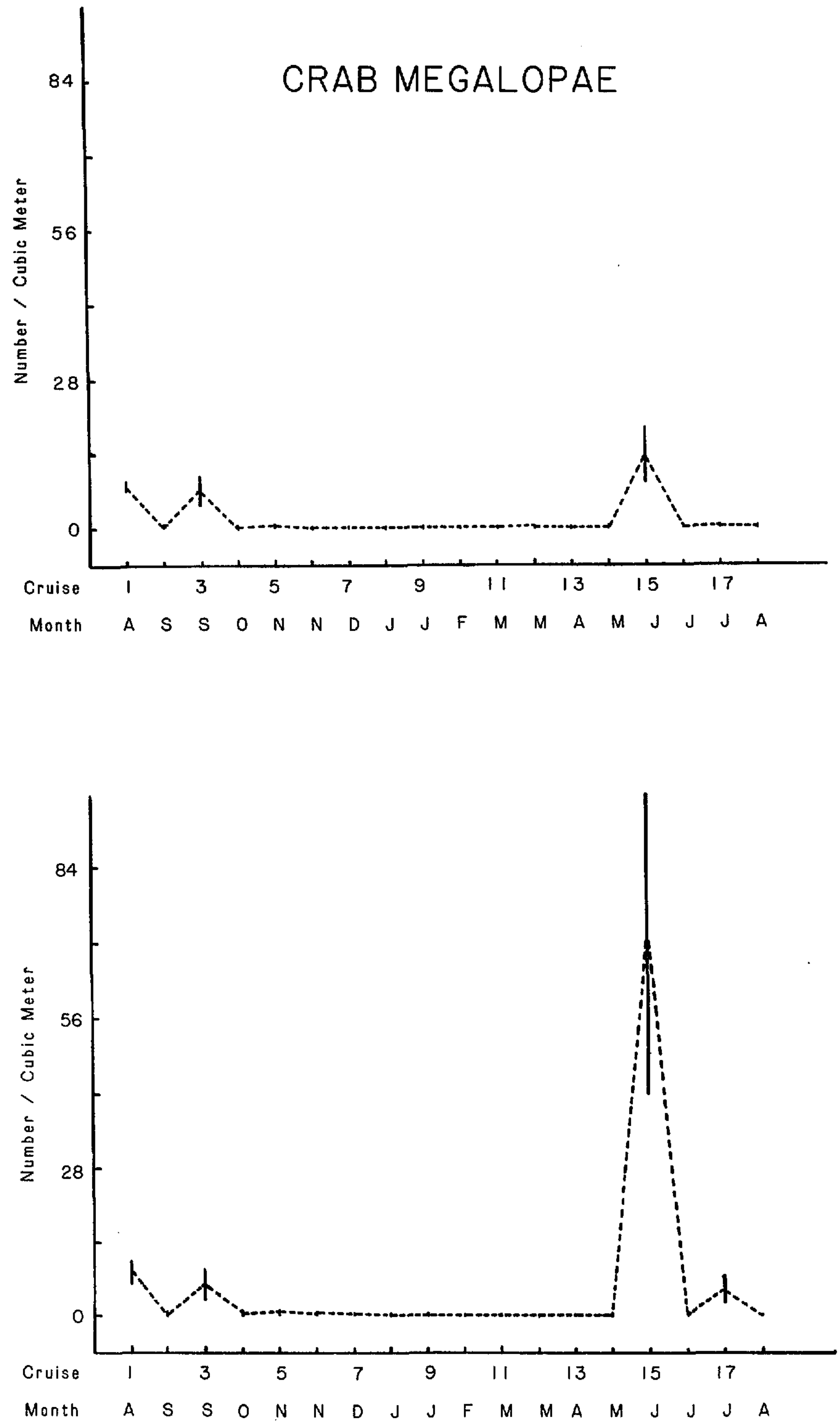


Figure 6-8. Mean densities (no./m^3) of crab megalopae in epibenthic sled collections on cruises 1 - 18 at NMF (above) and SJ (below). Vertical lines indicate plus or minus the standard error.

ties decreased after the early summer peak. SJ densities were greater than those at NMF. Sled and zooplankton net densities were comparable at NMF on all cruises, but they differed significantly at SJ in August when the zooplankton mean was about ten times larger than the sled mean. Large standard errors of the means indicate the magnitude of the variability between bihourly collections made over a 24 hour period.

Many species of crabs were represented in the megalopae collections, but fiddler crabs (*Uca spp.*) probably accounted for the largest proportion. Crab reproduction is often synchronized with lunar cycles (see references in Chapter 5), and with the frequency of sampling in this study, only a limited amount of information on megalopae abundance was obtained. Megalopae densities were low in September and November (Fig. 6-7 and 6-8), but they accounted for a large proportion of the catch (Table 6-1). Megalopae were the dominant organisms at SJ and second most abundant at NMF in June (Table 6-1).

C. STOMATOPODS

Stomatopods or mantis shrimps are morphologically, thus taxonomically, distinct from the decapod crustaceans. *Squilla empusa* is the only species regularly encountered in temperate estuaries. This lobsterlike animal lives in burrows in marsh creeks and tends to be more common in net catches after dark. Adults are usually from 60-150 mm in length. Sometimes large numbers of *S. empusa* are caught in commercial shrimp trawls in the ocean. Mantis shrimp or "thumbsplitters" (named for the damage inflicted by a sharp edge of the second leg) have large abdomens which are of commercial value in some areas.

Female stomatopods carry their eggs until they hatch. Developmental stages of *S. empusa* occur in the plankton throughout the warm season. Late larval stages (Fig. 6-6b) were collected in the epibenthic sled on most spring and summer cruises, but densities were always less than 1/m^3. No difference in the abundance of stomatopod larvae was seen between the two creeks.

D. CHAETOGNATHS

Chaetognaths or arrowworms were often the dominant organisms in sled collections at NMF and SJ (Table 6-1). These 'holo' forms were distributed throughout the water column, especially during the warm months. Densities of chaetognaths in sled and zooplankton collections are discussed in Chapter 5.

E. CTENOPHORES

Ctenophores or comb jellies are soft bodied, oval-shaped organisms. Adults are typically less than 100 mm in length and can be distinguished from true jellyfishes by the presence of rows of synchronously beating hairs or cilia. Ctenophores occur in most temperate high salinity estuarine and ocean areas. Calder and Burrell (1978) listed five species which occur in South Carolina waters. *Mnemiopsis leidyi* was frequently observed in NMF and SJ Creeks. This widely distributed ctenophore has been studied in the Chesapeake estuary by Bishop (1972), Miller (1974), and Burrell (1976). *Mnemiopsis* is a major predator of zooplankton, and high densities of ctenophores may strongly influence zooplankton abundance and distribution. *Beroe ovata,* a larger, less common comb jelly, consumes smaller ctenophores such as *Bolinopsis vitrea* (Swanberg, 1974) and *M. leidyi* (Sandifer et al. 1980).

Ctenophore densities are difficult to measure because the fragile animals break into amorphous fragments when they are caught in nets. Those which remain intact disintegrate when formalin preservative is added to the collection. No density information was recorded in the present study, but numbers were sometimes so large that several liters of jelly were caught in a tow. Large variations in numbers between consecutive tows indicated a patchy distribution in the water column.

F. CNIDARIANS

The true jellyfishes of the Phylum Cnidaria are usually more abundant than ctenephores in South Carolina estuaries. The taxonomy of the local cnidarians is summarized by Calder and Hester (1978). Large species such as *Stomolophus meleagris* (jellyball) and *Chrysaora quinquecirrha* (sea nettle) were frequently observed in Winyah Bay, SJ and NMF during the warm season. Large jellyfishes or medusae are relatively good swimmers and tend to occur in groups. Dozens of other medusae are less conspicuous because of their size and lack of pigmentation. Medusae were not enumerated in the sled samples, but *Bougainvillia sp.* and other small forms were occasionally very abundant. There was no evidence of vertical stratification by medusae in the marsh creeks.

G. MOLLUSCS

The Phylum Mollusca includes the common estuarine clams, snails, and squids. Most are benthic organisms which live on or in the sediment as adults. Since the epibenthic sled does not dig into the substrate, no adult molluscs were collected, but small (1-5 mm) clams and snails which had recently settled from planktonic larval stages (veligers) were swept into the sled net on most tows. Recently settled clams were not enumerated in the sample analyses; but they were most abundant from spring to fall. These molluscs were frequently identified in the guts of small bottom feeding fishes such as the spot and Atlantic croaker.

H. ANNELIDS

Polychaete worms are benthic organisms which, like molluscs, produce planktonic larval stages. Very few adult worms were collected with the sled, but late larval stages and small adults were not uncommon. It is not known whether some polychaetes swim just above the bottom or whether unburied worms become suspended and collected by the sled.

Leeches, which are also members of the Phylum Annelida, occurred in the majority of sled collections from November through March. *Calliobdella vivida* was frequently collected at both creeks. Free swimming adults (5-15 mm) were conspicuous in the samples and the same parasites were often observed attached to herring and menhaden fish hosts collected in the trawls. Densities were usually less than $1/m^3$.

I. FISHES

More than 100 species of fishes inhabit South Carolina estuaries (Poole, 1978) and the early life stages of many of these species inhabit marsh creeks like NMF and SJ. Fish eggs are difficult to identify and no attempt was made to distinguish species represented by eggs in the zooplankton and sled net collections. Most of those collected were planktonic (semibuoyant or free floating) types, but some demersal (adherant to bottom materials) eggs were also taken. Few eggs were collected during the cold months.

Fish larvae are generally less than 2 mm in length when they emerge from eggs. These fragile forms continue to absorb yolk material for days before they begin to feed. At this stage the larvae do not have the full adult complement of fin spines and rays and rarely resemble adults of the species in shape or color. Identification is usually very difficult until they reach several millimeters in length. The earliest developmental stages are weak swimmers and are distributed throughout the water column. The majority of estuarine species of fishes have strong affinities for the bottom as adults, and after they become strong enough swimmers, the larvae of these species occur closer to the substrate. The epibenthic sled is a relatively effective device for capturing fish larvae in the marsh creeks, but some caution must be taken in interpreting sled determined densities since avoidance of the collection apparatus by larvae probably results in only a fraction of the larvae being collected.

Fish larvae were identified to the lowest taxon possible and measured, and data on the seasonal occurrence and length frequency of larval fishes are discussed in Chapter 7.

In general, fish larvae (Fig. 6-9) followed a trend similar to that observed for shrimp larvae and megalopae. Low densities were typical during the cold months, and an abrupt increase in May and June marked an

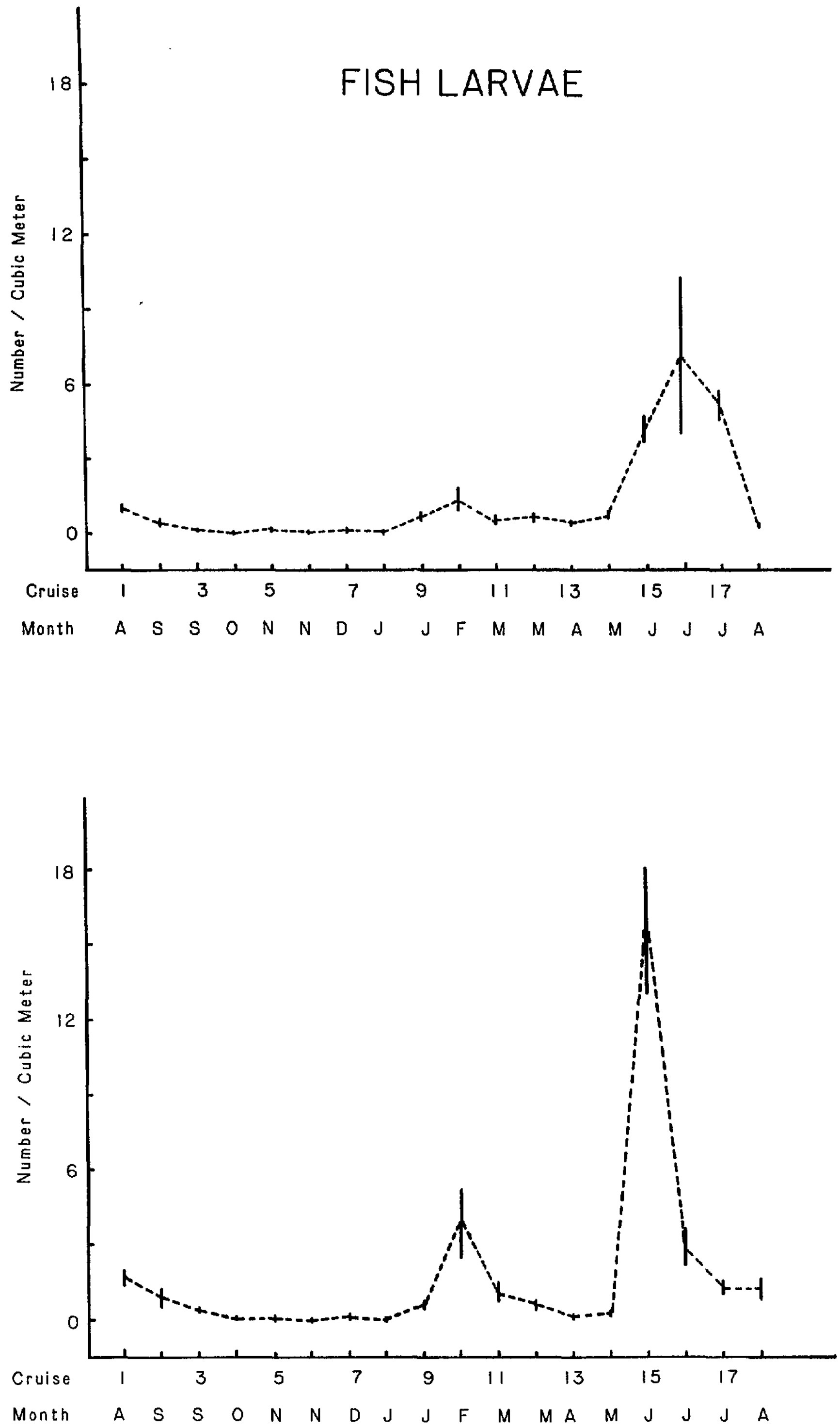


Figure 6-9. Mean densities (no./m^3) of fish larvae in epibenthic sled collections on cruises 1 - 18 at NMF (above) and SJ (below). Vertical lines indicate plus or minus the standard error.

early summer peak. Collections in early summer were dominated by anchovy (Fig. 6-6d), goby, and blenny larvae, but a great diversity of species was represented. The SJ peak was earlier and higher than the NMF peak, which persisted until later in the summer. The diversity and relative abundance of species was similar at both creeks.

The small February peaks at both creeks (Fig. 6-9) indicate an influx of young of the year spot larvae (Fig. 6-6c). Ocean-spawned spot migrate into estuaries in January and February each year (e.g., Weinstein, 1979), and numbers of these larvae are collected in the sled until spring, when they become too large and evasive to be captured with this device.

J. TOTAL ORGANISMS

The abundance of all organisms collected in the epibenthic sled samples is shown in Fig. 6-10. Maximum densities occurred in August, June, and July at both creeks and the presence of larval crustaceans, fishes, and chaetognaths account for these peaks (Table 6-1). Winter densities were generally less than twenty organisms per cubic meter; however, January peaks were prominent features of the seasonal curves for both creeks. These peaks represent the seasonal maxima for mysid shrimp (*Neomysis americana*) populations. Mysids were by far the most abundant organisms at both creeks on the December, January, March, and April cruises (Table 6-1). Without exception, total organisms densities were greater at SJ than at NMF (Fig. 6-10).

It is difficult to compare the actual densities of sled collected

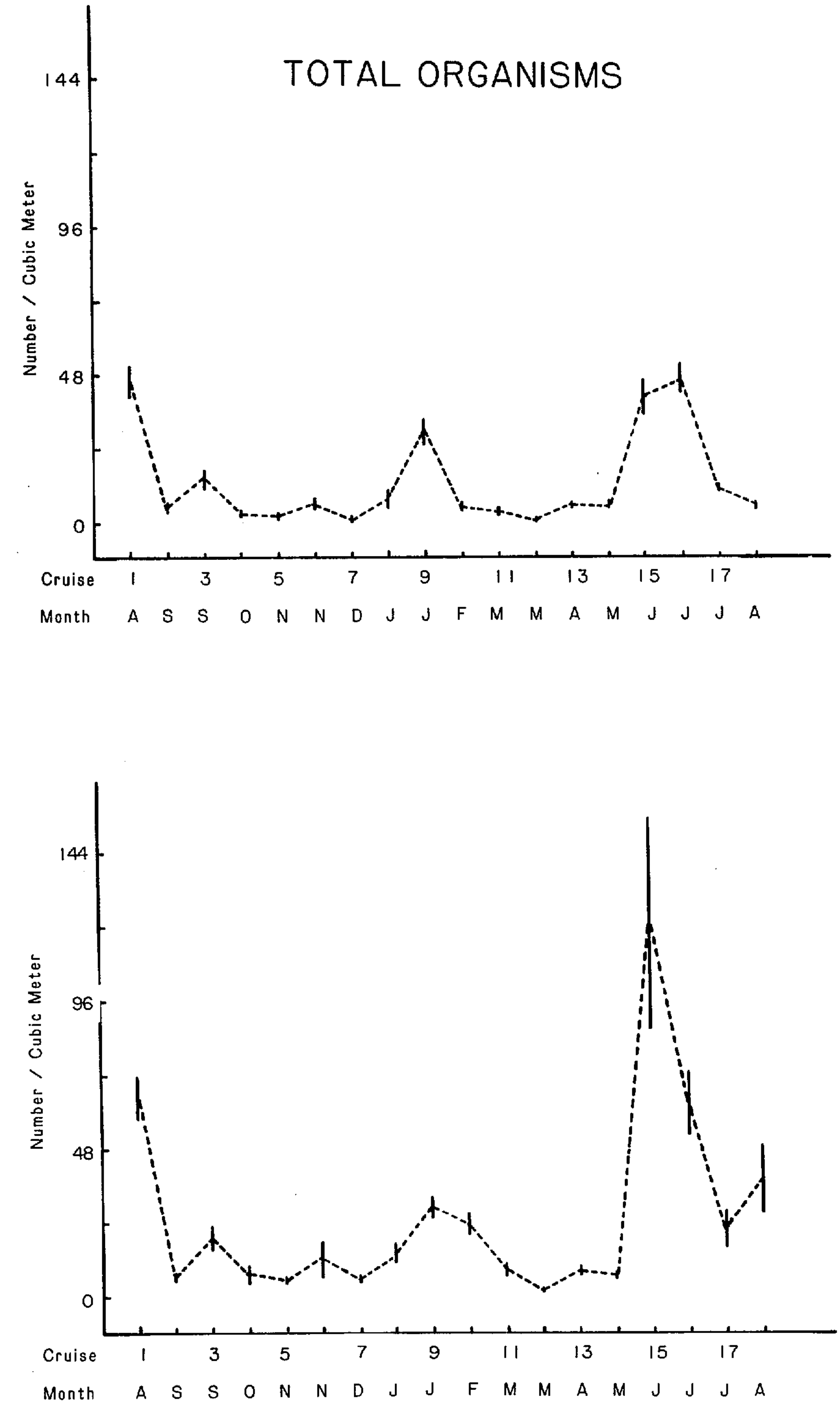


Figure 6-10. Mean densities (no./m^3) of total organisms in epibenthic sled collections on cruises 1 - 18 at NMF (above) and SJ (below). Vertical lines indicate plus or minus the standard error.

organisms at NMF and SJ to the abundance and distribution of similar organisms in other estuaries because so little quantitative information is available for other areas. This study appears to be the first comprehensive attempt to characterize the abundance of motile epibenthic populations in a South Carolina estuary, and the authors are not aware of any comparable studies from other east coast systems. Sled collections will be made at NMF, SJ, and some locations in Winyah Bay for the next several years to provide insight into the spatial and temporal variation in abundance and community structure.

Epibenthic organisms constitute important links in estuarine food webs by assimilating marsh productivity (plant detritus and microalgae) and making that energy available to higher trophic levels. It is important that more information about the ecology and physiology of these organisms is gathered so that their vulnerabilities to environmental perturbations can be assessed. What is already clear is that damage to pericarid crustacean and larval populations by pollutants would have far reaching implications for the survival of productive estuaries.

CHAPTER 7. SHRIMPS, CRABS, AND FISHES

The distribution, abundance, and survival of early life stages of shrimps, crabs, and fishes ultimately determine the success of the commercial and recreational fisheries. The occurrence of crustacean and fish larvae at NMF and SJ was discussed in Chapters 5 and 6. This information provides a background for the interpretation of the adult macroinvertebrate and fish collection data presented here. In this chapter, results of trawl and gill net collections made on major cruises at NMF and SJ are combined with general information on the ecology of three species of penaeid shrimps, the blue crab, a stomatopod, a squid, and eighty-five species of fishes.

I. SHRIMPS

The shrimp fishery ranks first in terms of value of all fisheries in South Carolina and in the United States (U.S. Dept. of Commerce, 1971-1980). The fishery is based on three species of penaeid shrimps which inhabit the southeast and Gulf coasts. Most of the commercial effort is concentrated in open coastal waters within a few kilometers of the shore, but shallow marsh estuaries are essential to the completion of the life cycle of penaeid shrimps. The life history strategies of the white, brown and pink shrimps are similar. Planktonic larvae develop from eggs spawned by adult shrimps in the ocean, and postlarval shrimps migrate into estuaries where they grow to adult size at a rapid rate. Adults are harvested in the estuaries and coastal waters during the warm months.

A. WHITE SHRIMP (*Penaeus setiferus*)

White shrimps occur in coastal waters from North Carolina to Mexico, but they are most abundant in the Gulf of Mexico adjacent to the Mississippi Delta. In South Carolina, white shrimps are usually the most important species in the fishery (U.S. Dept. of Commerce, 1971-1980).

Adult white shrimps spawn from May to September in ocean areas close to shore (Linder and Anderson, 1956). Large reproductively active white shrimps, referred to as "roe" shrimps, comprise a valuable spring fishery off South Carolina beaches.

The developmental sequence from egg-nauplius-protozoea-mysis-postlarva usually takes about two weeks. By the time the postlarval shrimps are about 7 mm in length, they have developed a stronger affinity for the bottom than the smaller planktonic stages (Williams, 1965). Postlarvae migrate from coastal waters into estuarine areas and grow at the rate of more than 1 mm per day. Postlarvae and small juvenile white shrimps tend to seek low salinity habitats within the estuary, but as the young shrimps mature, they move to saltier and deeper areas where they remain until they migrate back to the ocean as adults (Williams, 1955).

In late fall, juvenile and small adult white shrimps move to deep areas in the lower estuary where they overwinter. White shrimps are the most active of the penaeids and are known to migrate for considerable distances southward along the coast in the fall (Linder and Anderson, 1956). It is not known to what extent the spring coastal return migrations contributes to the local population, but white roe shrimp populations are probably composed of both overwintering residents and spring migrants.

White shrimps have a preference for soft mud over sandy or shelly substrates (Williams, 1958). Postlarvae, juveniles and adults eat algae, vascular plant detritus, and small invertebrates of many kinds, although they occasionally capture small fishes and squids (Williams, 1965).

White shrimps were by far the most abundant penaeids collected in NMF and SJ creeks during the summer and fall (Fig. 7-1). In August, similar numbers were collected in trawls at the two creeks (Fig. 7-1), but the NMF shrimps were smaller (Fig. 7-2) and weighed less (Fig. 7-3) than the SJ shrimps. Total numbers were greater in September, especially at SJ Creek (Fig. 7-1). The length frequency analysis for white shrimps in the September collections indicated that fewer small shrimps were present (Fig. 7-2). Mean length and weight of white shrimps was somewhat greater at NMF in the September collections (Fig. 7-2 and 7-3). White shrimp abundance and the length frequency structure remained unchanged on the November cruise (Fig. 7-1 and Fig. 7-2).

A large reduction in the abundance of white shrimps occurred before the December cruise and almost none were collected for the remainder of the trawl study (Fig. 7-1). Those collected from December to March were small individuals (Fig. 7-2).

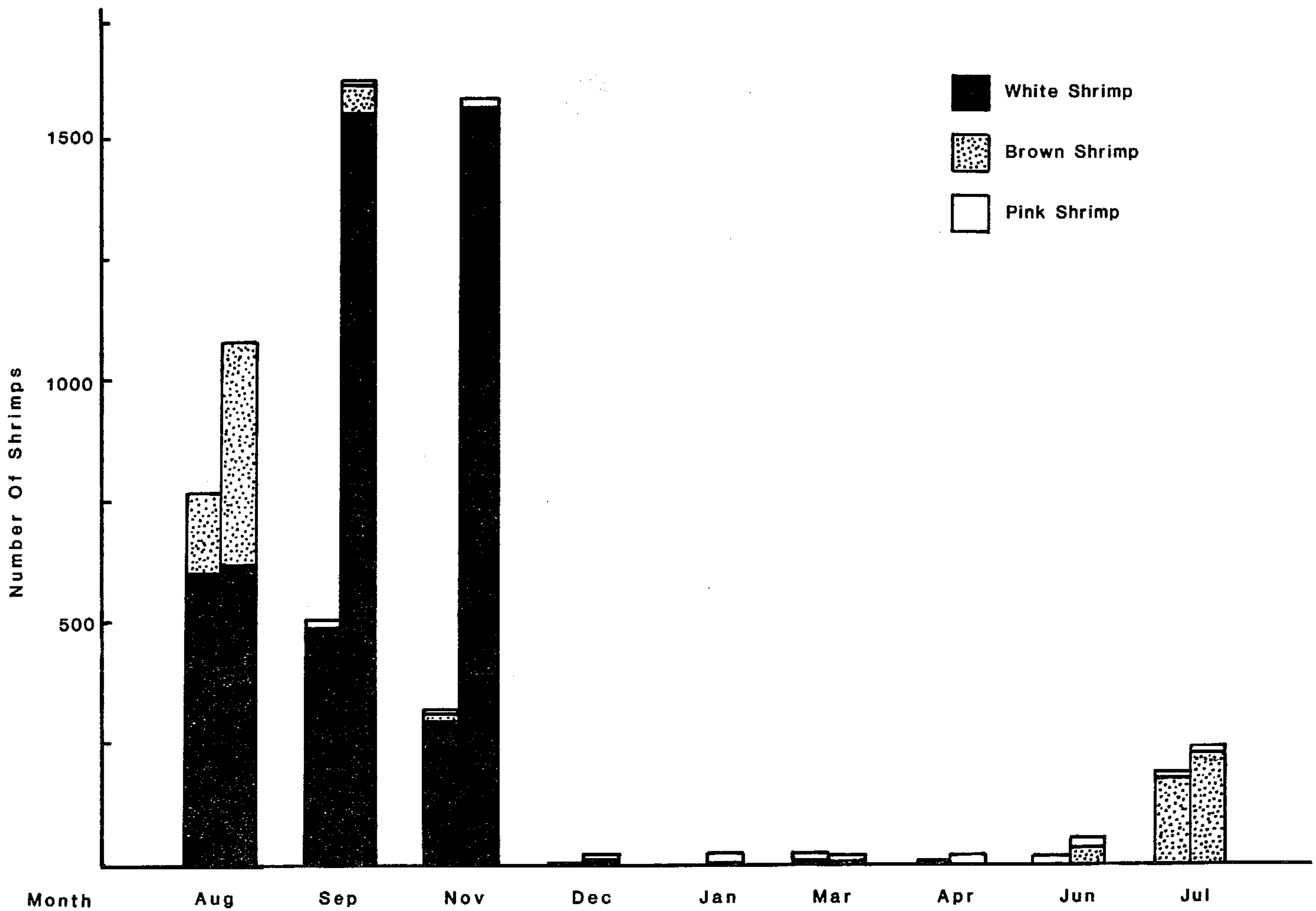


Figure 7-1. Total numbers of adult penaeid shrimps in trawl collections on major cruises. First column of each couplet indicates numbers for NMF, second column for SJ.

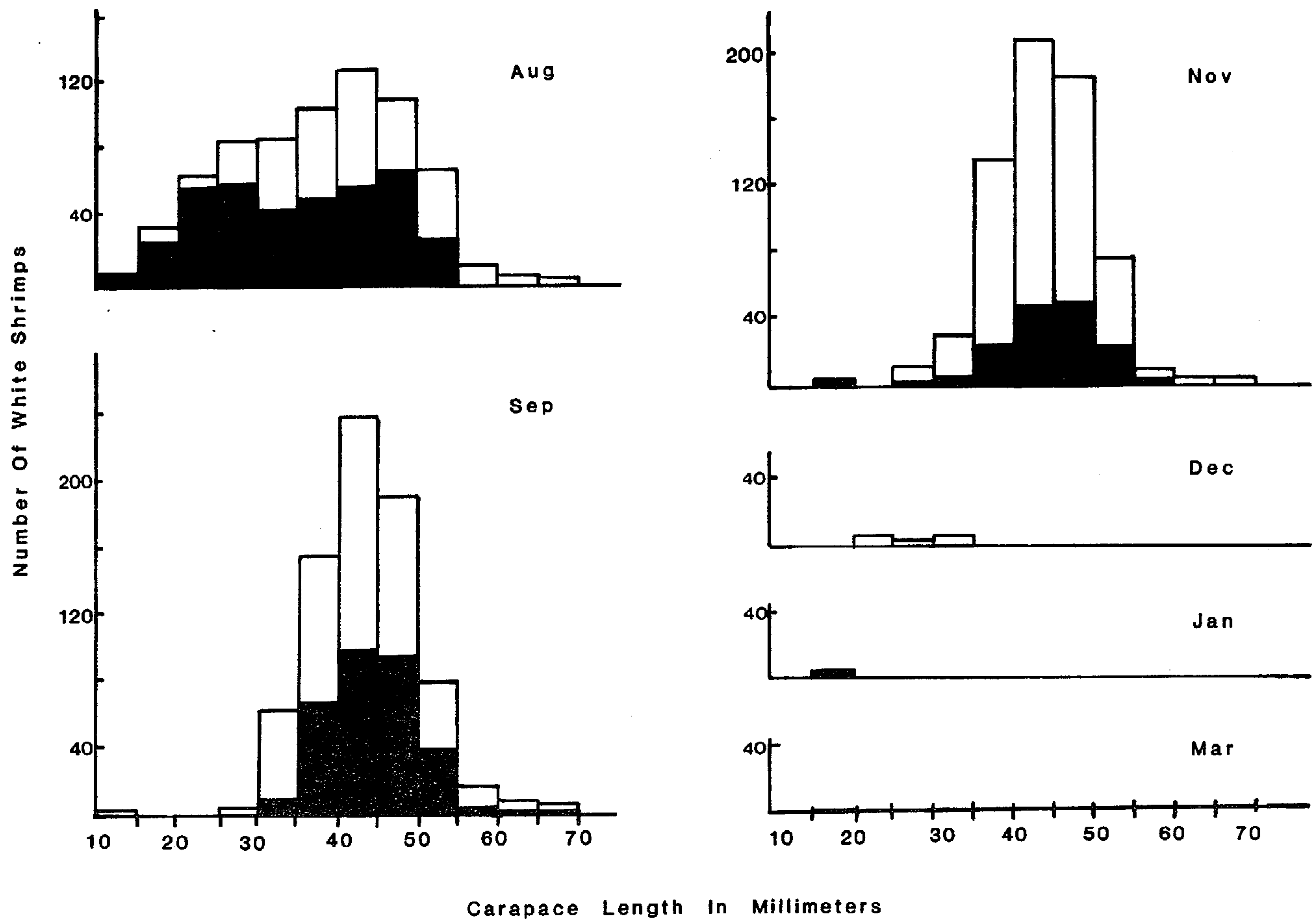


Figure 7-2. Length frequency analysis of white shrimps (*P. setiferus*) in trawl collections on major cruises at NMF and SJ. Height of each bar indicates total number of white shrimps of that size class at both creeks. Shaded portion of each bar represents number collected at NMF.

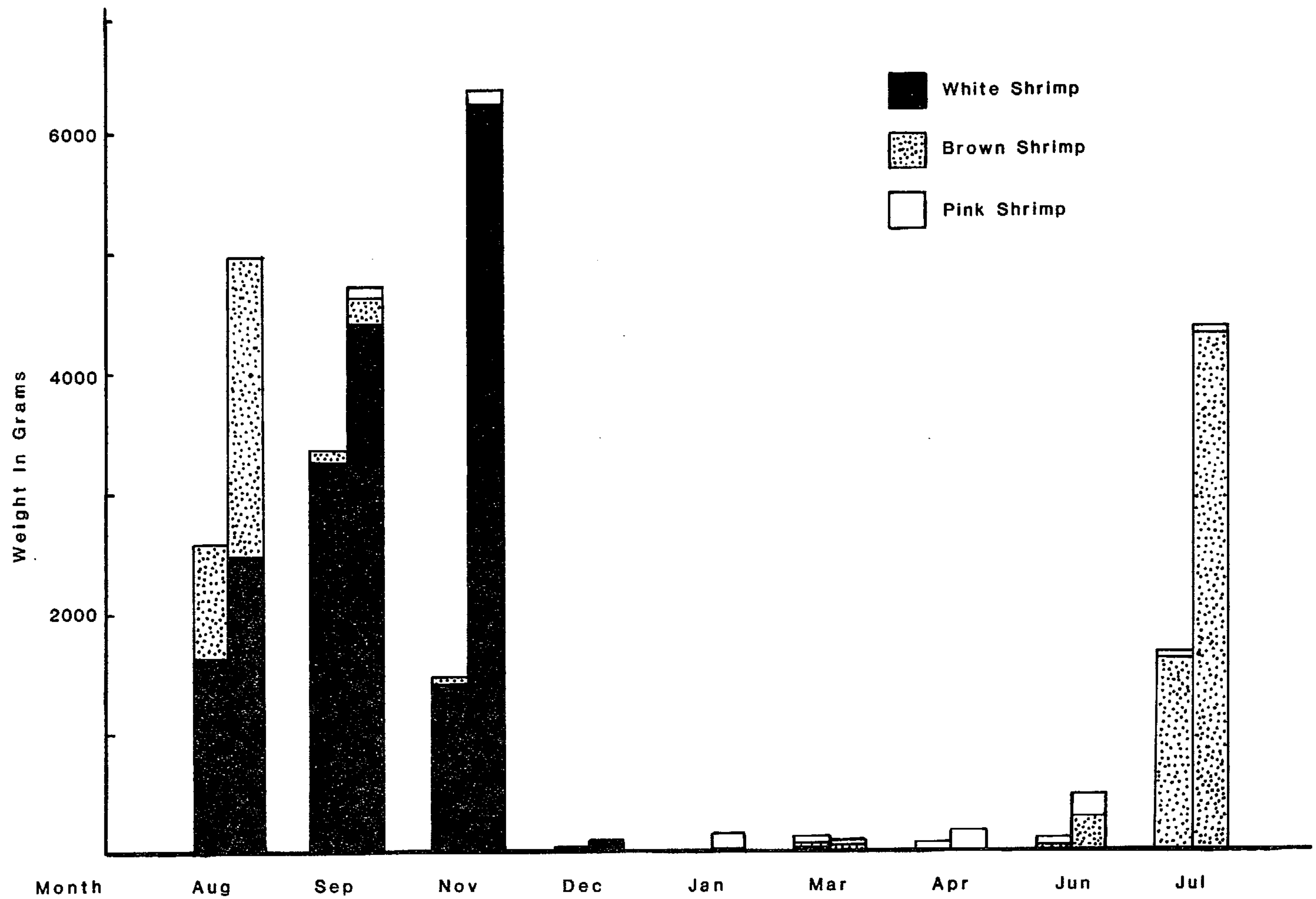


Figure 7-3. Total weight of adult penaeid shrimps in trawl collections on major cruises. First column of each couplet indicates numbers for NMF, second column for SJ.

The seasonal pattern of abundance reported here is consistent with the general pattern for white shrimp distribution. Juvenile and young white shrimp populations were established in the creeks before the first samples were collected in August. Increasing numbers of adults moved into the high salinity creeks, presumably from lower salinity regions of Winyah Bay. Decreasing temperatures in November probably triggered a migration of adult white shrimps to the ocean, but some young shrimps remained in the creeks through the winter.

White shrimps were consistently more abundant at SJ Creek. The total number of white shrimps collected on each cruise increased from August to November at South Jones Creek, but decreased at No Man's Friend (Fig. 7-1). Of the more than 5100 white shrimps analyzed in the study, more than 3700 (73%) were collected at SJ Creek.

B. BROWN SHRIMP (*Penaeus aztecus*)

Brown shrimps occur from North Carolina to South America. Adults spawn in deep coastal waters during the winter, and, although postlarvae have been collected in North Carolina estuaries from October to May, peak recruitment is in early spring (Williams, 1959). Bearden (1961) reported peak abundance for brown shrimp larvae in South Carolina estuaries in February and March. Postlarvae, which arrive in shallow marsh waterways during the coldest periods, probably die (Williams, 1955). Growth rates for postlarval brown shrimps (1.5 mm/day) may be somewhat greater than those measured for white shrimps (Williams, 1955).

In South Carolina, brown shrimps do not inhabit low salinity estuarine areas which are sought by white shrimps later in the warm season. Brown shrimps are burrowers and seem to be more abundant on sandy mud substrates than on soft mud bottom.

The temporal segregation of the white and brown shrimps is distinct in most areas. Brown shrimps occupy the estuarine nursery grounds in early summer and adults leave the area by early fall. As adult brown shrimp abundance in the creeks decreases, young white shrimps arrive. This pattern was observed at both NMF and SJ Creeks (Fig. 7-1).

On the August cruise, adult brown shrimps were about twice as abundant at SJ Creek, but the numbers collected at both creeks were less than those for white shrimps (Fig. 7-1). The mean size and weight of brown shrimps in August was greater than those for white shrimps (Fig. 7-2, 7-3, 7-4). In September, few brown shrimps were collected. Very few small individuals remained in the creeks during the cold months. Postlarval brown shrimps were collected with the epibenthic sled in March. Juveniles occurred in trawl collections on the spring cruises and adults were collected in June and July. The large increase in the number of adult brown shrimps from June to July is probably related to the movement of individuals into the creeks from adjacent shallow flats where juveniles appeared to be more abundant. The mean carapace length of all brown shrimps caught in June was about 33 ± 5 mm and the mean length in July was about 42 ± 6 mm.

C. PINK SHRIMP (*Penaeus duorarum*)

The pink shrimp has a discontinuous geographical distribution between

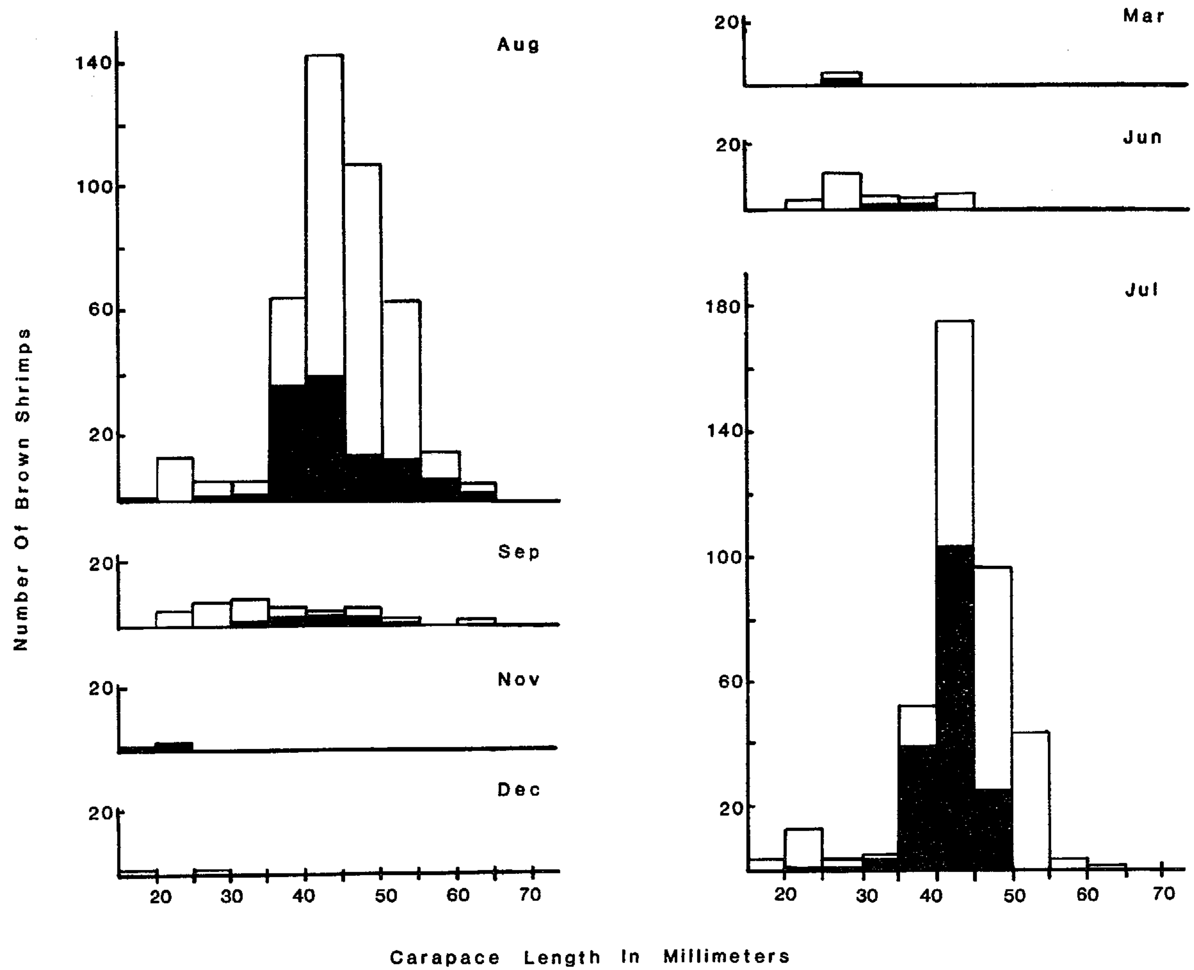


Figure 7-4. Length frequency analysis of brown shrimps (*P. aztecus*) in trawl collections on major cruises at NMF and SJ. Height of each bar indicates total numbers of brown shrimps of that size class at both creeks. Shaded portion of each bar represents number collected at NMF.

North Carolina and South America. Endemic populations large enough to support commercial fisheries occur in North Carolina, Key West, and Campeche (Mexico). South Carolina densities are comparatively small and the pink shrimp accounts for less than 5% of the total landings (Sandifer et al., 1980).

The spawning season of the pink shrimp is similar to that of the white shrimp, May through September (Williams, 1965). Postlarvae enter South Carolina estuaries from May through September (Bearden, 1961b) and move from shallow, less saline areas to deeper creeks and channels closer to the ocean as they mature (Williams, 1965).

Pink shrimps inhabit coarser substrates than white shrimps and often remain completely buried (Williams, 1958). This relatively inactive penaeid overwinters in high salinity estuarine areas. In North Carolina overwintering populations are sometimes killed by extreme cold, but in the spring, adults migrate to ocean spawning grounds (Williams, 1965).

Pink and white shrimps inhabit the estuaries at the same time, but apparently reduce competition for space and resources by favoring different habitats. Pink shrimp catches at NMF and SJ were small (Fig. 7-1), yet some individuals occurred on all but the August and December cruises. Pink shrimps were about five times more abundant at SJ.

The one-half inch mesh of the trawl net did not retain a high percentage of the juvenile or small adult penaeid shrimps which passed into the mouth of the trawl. Adult shrimps have very strong avoidance capabilities and length frequency of blue crabs taken on all cruises is shown in Fig. 7-5. The majority of trawl caught crabs were juveniles less than 60 mm in width. Young crabs less than 20 mm in width dominated the collections in November and January. These small crabs represented summer and early fall spawned young of the year. Large numbers of young were collected throughout the cold months, but most had grown to more than 20 mm in width by March. The low numbers of juveniles collected in March and the absence of small crabs in April indicated the lack of recruitment to the population during the winter. This observation is consistent with the analysis of the zooplankton and sled collections.

Adult crabs avoided the trawl and few were collected on any cruise. All but a few adult blue crabs captured in the trawl and gill net were males. No general relationship between number or sex of adult blue crabs and salinity was observed during the study. The dominance of male crabs in these high salinity creeks is not consistent with the classic distribution of blue crabs described for other estuaries (e.g., Van Engel, 1958).

Crabs of all sizes were most abundant in the tidal creeks during the cold months. From late spring through fall, crabs appear to be more active and spend more time along shallow banks and on the marsh surface. The concentration of relatively slow moving crabs in the creeks during the cold months may account for larger catches from November through April than from June through September.

With the exception of the August cruise, blue crabs of most sizes were more abundant in NMF than SJ Creek (Fig. 7-5). About 1400 crabs were analyzed from all collections and about 900 (65%) were from NMF sam-

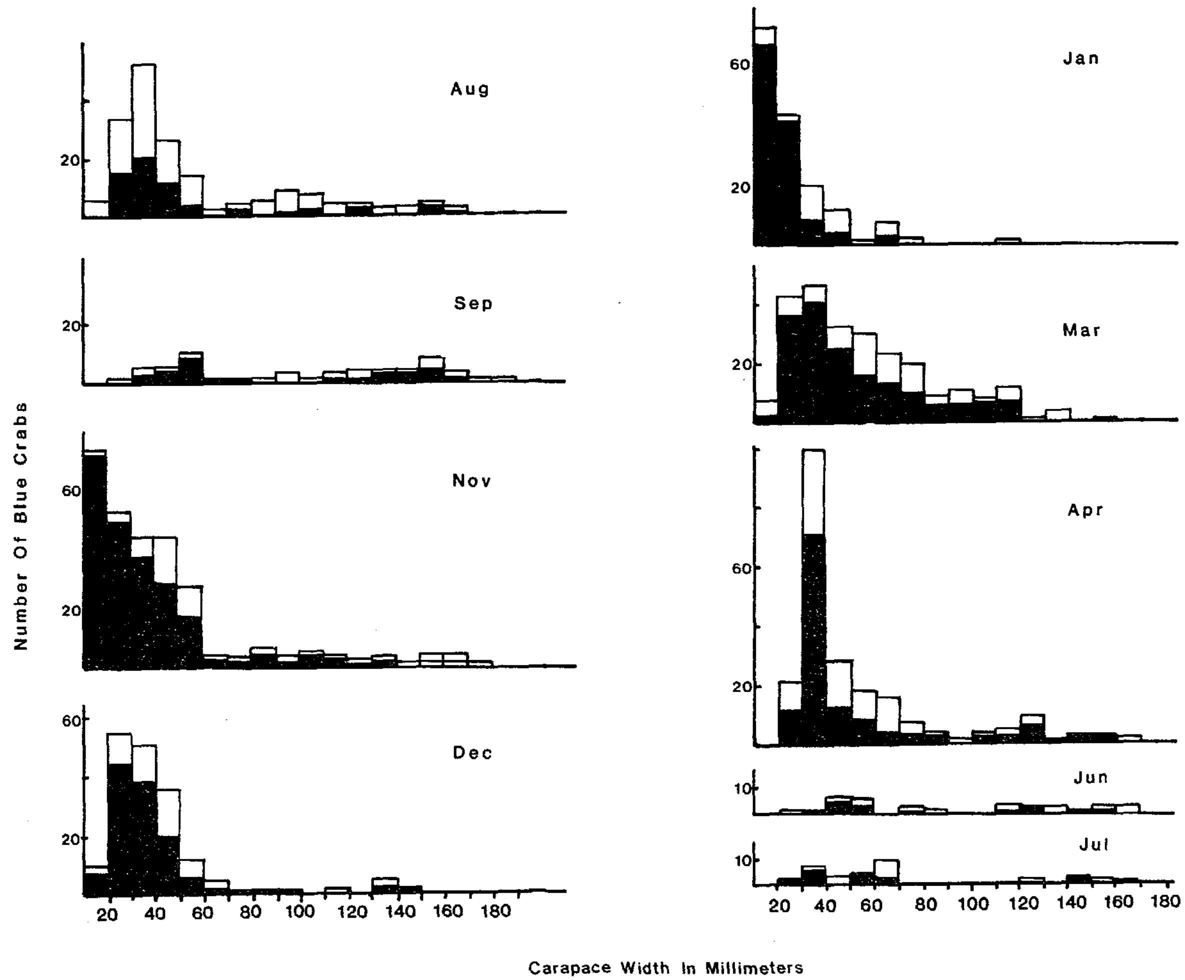


Figure 7-5. Length frequency analysis of blue crabs (*C. sapidus*) in trawl collections on major cruises at NMF and SJ. Height of each bar indicates total number of blue crabs of each size class at both creeks. Shaded portion of each bar represents numbers collected at NMF.

ples. Juvenile crabs less than 30 mm width were especially abundant at NMF.

The role of the blue crab in estuaries is extremely important. Crabs are opportunistic organisms which procure food through scavenging and predation; they may compete with shrimps and fishes for food and space. The influence of blue crabs on other estuarine organisms is difficult to measure, but field and laboratory observations of their aggressive life style indicate that blue crabs must play a major regulatory role within the ecosystem.

In addition to the blue crab, other brachyuran crabs were collected in trawl samples at both creeks. These included other portunid crabs (*Ovalipes ocellatus, Portunus gibbesii, P. spinimanus,* and *Callinectes similis*), majid crabs (*Libinia emarginata* and *L. dubia*), and xanthid crabs (*Panopeus herbstii* and *Eurypanopeus depressus*). These species were most abundant during the summer, but none was collected in sufficient numbers to suggest it was a common inhabitant of the creek bottoms. However, small xanthids like *Panopeus* were not effectively sampled with the trawl and other observations indicate that xanthid crabs are very abundant on subtidal oyster and shell bottoms in certain parts of the creeks. Adult hermit crabs were conspicuous by their absence in both creeks.

III. STOMATOPOD OR MANTIS SHRIMP (*Squilla empusa*)

Adult stomatopods were regularly collected in trawls from January through November. Some 80-120 mm adults were caught from January through June, but the greatest numbers occurred from August through November.

Stomatopods were usually more common in night tows than daylight collections. They appeared to be equally abundant at the two creeks. Stomatopods were probably much more abundant than trawl collections indicated. The abundance and distribution of stomatopod larvae was discussed in Chapter 6.

IV. SHORT-FINNED SQUID (*Lolliguncula brevis*)

Squid are fast swimming shell-less molluscs which easily escape otter trawls; however, the short-finned squid was caught in most trawl collections from April through November at both creeks. A total of 251 individuals greater than 30 mm in mantle length were recorded during the study. The largest collections were in April when similar numbers of 50-110 mm (mantle length) squid occurred at both creeks. Adults with eggs were taken in June and very small squid (<10 mm) were found among bottom debris in July trawls. Squid may migrate to deeper estuarine and coastal areas during the coldest months.

Although squid constitute a significant portion of the shrimp fishery by catch, they have little or no commercial value. Squid are used for bait by local anglers. Gut contents of gars, bluefishes and flounders caught in gill nets at both creeks frequently included squid.

V. FISHES

Although the finfish fisheries of South Carolina are not as large as the shrimp and crab fisheries, many important commercial and sport fish species occur in the estuaries and shallow ocean. More than 100 species of fishes are known from the inshore waters of South Carolina (Poole,1978).

In this study, information on the fishes of NMF and SJ Creeks was gathered from epibenthic sled, otter trawl, and gill net collections. Between the three gear types, 85 species of fishes were identified. The identification and length frequency analyses of larval stages collected in the sled were instrumental in assessing the utilization of these creeks by many of the 65 species caught with the trawl and 24 species caught in the gill nets. This information is summarized in Table 7-1. General comments on the life history, distribution, and relative abundance of each species is presented in an annotated list of the fishes. The species are discussed in the order in which they appear in Table 7-1.

A great deal of information on the ecology and life history of most of the species which were collected in the creeks is available in the scientific literature, but we have cited only those studies which deal with broad aspects of their ecology. For further information on most of these species, the reader is referred to Hildebrand and Schroeder (1928), Bigelow and Schroeder (1953), Böhlke and Chaplin (1968), Dahlberg (1975), and Hoese and Moore (1977).

The first part of this section is the annotated list of species. This is followed by a discussion of fish community dynamics and a comparison of the results of the NMF-SJ study with others conducted in Winyah Bay and neighboring estuaries.

A. ANNOTATED LIST OF FISHES

Cartilaginous fishes such as sharks, rays and skates are relatively

Table 7-1. Taxonomic list of fishes collected with all gear types from August 1980 through July 1981. X indicates presence at No Man's Friend (NMF) and South Jones (SJ) Creeks, in trawls, in gill nets (GN), in epibenthic sled or zooplankton nets (SL/PLK). OCC. represents the number of times the species occurred in trawl collections on major cruises at either creek out of a total of 18 samplings (9 at NMF, and 9 at SJ).

FAMILY	GENUS-SPECIES	COMMON NAME	NMF	SJ	TRAWL	GN	SL/PLK	OCC.
Carcharhinidae	*Carcharhinus obscurus*	dusky shark	X			X		1
	Rhizoprionodon terraenovae	Atlantic sharpnose shark	X	X		X		4
Sphyrnidae	*Sphyrna lewinii*	scalloped hammerhead	X	X		X		2
Dasyatidae	*Dasyatis americana*	southern stingray	X	X		X		4
	Dasyatis centroura	roughtail stingray	X			X		1
	Dasyatis sabina	Atlantic stingray	X	X	X	X		4
Myliobatidae	*Rhinoptera bonasus*	cownose ray	X	X		X		2
Lepisosteidae	*Lepisosteus osseus*	longnose gar	X	X	X	X		5
Elopidae	*Elops saurus*	ladyfish	X	X	X	X	X	4
	Megalops atlantica	tarpon		X			X	0
Anguillidae	*Anguilla rostrata*	American eel		X	X		X	4
Ophichthidae	*Bascanichthys sp.*	whip eel		X	X			1
	Myrophis punctatus	speckled worm eel	X	X			X	0
	Ophichthus gomesi	shrimp eel	X	X	X		?	1
Clupeidae	*Alosa aestivalis*	blueback herring	X	X	X		?	6
	Brevoortia tyrannus	Atlantic menhaden	X	X	X	X	?	14
	Dorosoma cepedianum	gizzard shad		X	X		?	2
	Dorosoma petenense	threadfin shad		X	X		?	1
Engraulidae	*Anchoa hepsetus*	striped anchovy	X	X	X		X	9
	Anchoa mitchilli	bay anchovy	X	X	X		X	17
Synodontidae	*Synodus foetens*	inshore lizardfish	X	X	X		X	7
Ariidae	*Arius felis*	sea catfish	X	X	X	X		7
	Bagre marinus	gafftopsail catfish		X		X		1
Batrachoididae	*Opsanus tau*	oyster toadfish	X	X	X			13
Gobiesocidae	*Gobiesox strumosus*	skilletfish	X	X	X		X	1
Gadidae	*Urophycis floridanus*	southern hake	X	X	X			6
	Urophycis regius	spotted hake	X	X	X			2
Ophidiidae	*Rissola marginata*	striped cusk-eel	X	X	X			6
Cyprinodontidae	*Cyprinodon variegatus*	sheepshead minnow		X	X			1
	Fundulus heteroclitus	mummichog	X	X	X		?	
Atherinidae	*Membras martinica*	rough silverside		X			X	0
	Menidia menidia	Atlantic silverside	X	X	X		X	5
Syngnathidae	*Syngnathus floridae*	dusky pipefish	X	X	X		X	3
	Syngnathus fuscus	northern pipefish	X		X		X	1
	Syngnathus louisianae	chain pipefish	X	X	X		X	3
Serranidae	*Centropristis philadelphica*	rock sea bass	X		X			1
	Mycteroperca microlepis	gag grouper		X	X		X	3
Pomatomidae	*Pomatomus saltatrix*	bluefish	X	X	X	X		7
Rachycentridae	*Rachycentron canadum*	cobia		X	X			1
Carangidae	*Caranx hippos*	crevalle jack	X	X	X	X		5
	Chloroscombros chrysurus	Atlantic bumper	X	X	X			5
	Selene vomer	lookdown	X	X	X			2
Lutjanidae	*Lutjanus griseus*	gray snapper		X	X		X	1
Gerreidae	*Diapterus olisthostomus*	Irish pompano	X	X	X			2
	Eucinostomus argenteus	spotfin mojarra	X	X	X		?	3
	Eucinostomus gula	silver jenny		X	X		?	1
Pomadasyidae	*Orthopristis chrysoptera*	pigfish	X	X	X		X	2
Sparidae	*Archosargus probatocephalus*	sheepshead	X	X	X		X	5
	Lagodon rhomboides	pinfish	X	X	X		X	11

Table 7-1 cont.

FAMILY	GENUS-SPECIES	COMMON NAME	NMF	SJ	TRAWL	GN	SL/PLK	OCC.
Sciaenidae	*Bairdiella chrysura*	silver perch	X	X	X		X	14
	Cynoscion nebulosus	spotted sea trout	X	X	X	X	X	10
	Cynoscion regalis	weakfish	X	X	X	X	X	1
	Leiostomus xanthurus	spot	X	X	X	X	X	17
	Menticirrhus americana	southern kingfish		X	X	X	X	2
	Menticirrhus littoralis	gulf kingfish		X		X		1
	Menticirrhus saxatilis	northern kingfish		X	X	X		2
	Micropogonias undulatus	Atlantic croaker	X	X	X	X	X	11
	Pogonias cromis	black drum		X	X			1
	Scianops ocellata	red drum	X	X	X		X	3
	Stellifer lanceolatus	star drum	X	X			X	0
Ephippidae	*Chaetodipterus faber*	Atlantic spadefish	X	X	X			5
Mugilidae	*Mugil cephalus*	striped mullet		X	X	X	X	3
	Mugil curema	white mullet	X	X	X			6
Blenniidae	*Hypsoblennius hentzi*	feather blenny	X	X	X		X	3
	Chasmodes bosquianius	striped blenny		X			X	0
Gobiidae	*Gobionellus boleosoma*	darter goby	X	X			X	0
	Gobionellus nastatus	sharptail goby	X	X	X		X	1
	Gobionellus shufeldti	freshwater goby	X	X			X	0
	Gobiosoma bosci	naked goby	X	X	X		X	2
	Gobiosoma ginsburgi	seaboard goby	X	X			X	0
	Microgobius gulosus	clown goby		X			X	0
	Microgobius thalassinus	green goby		X			X	0
Scombridae	*Scomberomorus maculatus*	Spanish mackerel		X	X			1
Stromateidae	*Peprilus alepidotus*	harvestfish		X	X			1
	Peprilus triacanthus	butterfish		X	X			1
Triglidae	*Prionotus tribulus*	bighead searobin	X	X	X		X	4
Bothidae	*Ancyclopsetta quadrocellata*	ocellated flounder	X	X	X			5
	Citharichthys spilopterus	bay whiff	X	X	X		X	7
	Etropus crossotus	fringed flounder	X	X	X			12
	Paralichthys dentatus	summer flounder	X	X	X	X	X	4
	Paralichthys lethostigma	southern flounder	X	X	X	X	X	15
Soleidae	*Trinectes maculatus*	hogchoker	X	X	X		X	8
Cynoglossidae	*Symphurus plagiusa*	blackcheek tonguefish	X	X	X		X	17
Balistidae	*Monacanthus hispidus*	planehead filefish		X			X	0
Tetraodontidae	*Sphoeroides maculatus*	northern puffer	X				X	0

large, slow swimming seasonal migrants to the study area. Three species of sharks and three species of stingrays were caught in gill nets at NMF and SJ Creeks. Bearden (1965) summarized information on the elasmobranch fishes of South Carolina.

A 750 mm dusky shark (*Carcharhinus obscurus*) collected in July at NMF constituted the only record for this common coastal shark. Fish fragments were found in its gut. Young and small adult dusky and other carcharhinid sharks are common in high salinity estuarine areas of South Carolina.

Atlantic sharpnose sharks (*Rhizoprionodon terraenovae*) are the most common small sharks in the salt marsh creeks and lower estuaries of South Carolina. Adults release young in the spring and large numbers of 350-600 mm individuals were collected in gill nets from June through September. These voracious predators consumed shrimps, crabs, and a variety of fishes. Young sharpnose sharks were equally abundant at NMF and SJ. In the fall, sharpnose sharks apparently migrate to deeper and warmer waters.

Scalloped hammerheads (*Sphyrna lewinii*) were common in gill net catches in July and August. Individuals from 410-480 mm were more common at SJ than NMF. These young sharks probably originated from adult spawning activity in the ocean during the spring. Gut contents included penaeid shrimps and small fishes, especially menhaden.

Southern stingrays (*Dasyatis americana*) were collected in several gill net sets in August and September; however, because of their large size, these rays may have been more abundant than the gill net catches indicated. Individuals ranged from 360-620 mm in width and usually contained crushed clam shells (*Macoma baltica*). Southern stingrays occurred at both creeks. One specimen (410 mm) of the roughtail stingray (*Dasyatis centroura*), a close relative of the southern stingray, was collected in a gill net in August at NMF.

The most common ray was the Atlantic stingray (*Dasyatis sabina*). Small rays with wing widths of 220-380 mm were frequently caught in gill nets from April through November. On one occasion in August, a 370 mm female released three full term 130 mm young while being removed from the net. Atlantic stingrays, also known as stingarees, may be year-round residents of estuaries. They are collected in low salinity portions of Winyah Bay as well as in the ocean. These rays occur on mud and sand bottoms and consume a variety of shrimps, crabs, and relatively slow moving benthic invertebrates.

Cownose rays (*Rhinoptera bonasus*) were caught in August at SJ Creek. These fishes were 550-680 mm in width. Gut contents included clam shell fragments (*Macoma baltica*). Cownose rays are major predators of clam populations and have been known to decimate large numbers of commercially valuable hard clams (*Mercenaria mercenaria*) in northern estuaries.

The longnose gar (*Lepisosteus osseus*) was caught in gill nets, and occasionally in trawls, at both creeks. Gars are primarily freshwater fishes, but are often found in brackish and high salinity estuarine areas. The maximum size for this species is about 1500 mm; however, the range for those caught in the study area was 650 to 930 mm. This predator usually swims well above the bottom, and its presence is often revealed by its disturbance of the surface. Shrimps and fishes (especially menhaden) were usually in the guts of captured individuals. Gars are probably year-round residents of the estuary, but none were caught during the winter at either creek.

Ladyfish (*Elops saurus*) are sleek silvery gamefish which are common in southeastern estuaries. Larvae were collected with the sled in December and June, and small juveniles were caught in cast nets and minnow traps in marsh pools during most of the warm season. Gehringer (1959) described the early development of ocean-spawned larvae. Adults are fast swimming predators which avoid trawls, but 220-350 mm individuals were occasionally snagged in gill nets from spring through fall.

A 22 mm tarpon (*Megalops atlantica*) larva (leptocephalus) was collected with the sled in August at SJ. Large tarpon are summer visitors to the ocean adjacent to Winyah Bay. It is not known whether any spawning occurs locally, yet larval and juvenile tarpon (to about 300 mm) are commonly caught in upper marsh waterways during the summer.

The American eel (*Anguilla rostrata*) may be one of the most abundant fishes in coastal marshes and estuaries, but because they are secretive and are not well retained by trawl nets, the assessment of population densities is difficult. These year-round residents are especially common around marsh banks and submerged obstructions. Postlarval elvers or glass eels were collected in January, February and April with the sled at SJ. Young eels migrate from spawning grounds in the deep Atlantic Ocean near Bermuda. Eels are predators of many species of shrimps, crabs and fishes. American eels have been found in the guts of red drum, hammerhead sharks, and oyster toadfish in the study area. The potential for a major commercial eel fishery in Winyah Bay appears to be very good, but preliminary trapping surveys need to be conducted.

Three species of ophichthid eels were collected at South Jones Creek. One shrimp eel (*Ophichthus gomesi*) and one whip eel (*Bascanichthys sp.*) were captured in September with the trawl. Little is known about the ecology of either species, but they do not appear to be common in this region. Speckled worm eels (*Myrophis punctatus*), however, are abundant in the marsh creeks of North Inlet all year. None of these relatively small eels were taken in trawls, but adults are commonly observed in muddy intertidal substrates. Leptocephalus larvae (40-70 mm) were collected in the majority of epibenthic sled tows from November through March at both creeks.

The herrings comprise a well known family of estuarine and coastal fishes. Two of the four species collected in the two creeks, blueback herring (*Alosa aestivalis*) and Atlantic menhaden (*Brevoortia tyrannus*) are of commercial importance. A close relative of the blueback is the American shad (*Alosa sapidissima*), and, although this anadromous species was not collected in this study, it is common in Winyah Bay. A spring shad fishery intercepts adults moving from the ocean to river spawning grounds. Blueback herring follow the same pattern. The young of both species move from freshwater hatching areas to brackish and high salinity areas where they remain for about one year. Young of the year bluebacks (<120 mm) were taken in trawl collections during December, January, April, June, and August. Small larvae of either the blueback or American shad were collected in April with the sled at No Man's Friend Creek.

Other clupeid (herring) larvae which were identified as Atlantic menhaden were collected in January, March, and April in both creeks. Menhaden are one of the dominant species in the Winyah Bay area. Individuals of all sizes occur from many miles into the ocean to the freshwater extreme of the estuary.

Spawning probably takes place in the fall. Some adults with roe (eggs) were collected in gill nets in the creeks on the August and September cruises. Egg release usually occurs in high salinity areas and larvae move into estuarine nursery grounds (Nelson et al., 1977). Even though juvenile menhaden are good swimmers which easily avoid nets, many 50-150 mm fishes were taken in trawl collections in both creeks. Hundreds of menhaden of the same size were caught in the fine mesh gill nets during most cruises. Sometimes creek surface waters were darkened and agitated by schools of small menhaden. Hand seines and purse seines are the most appropriate gear types for catching menhaden. Large commercial purse seine fleets harvest tons of adult menhaden from waters off of Winyah Bay each summer. Schools can be seen swimming near the surface year round, but the largest fishes migrate south along the coast as temperature declines. Nicholson (1978) described the dynamics of populations along the coast.

The ecological significance of menhaden in estuaries is great because they filter microscopic algae and marsh plant detritus from the water (Peters and Schaaf, 1981) and assimilate that energy into a form of protein which can be utilized by consumers higher in the food web. Filter feeding menhaden may also influence zooplankton communities. The migration of adult menhaden makes estuarine produced protein available to ocean predators, thus providing a crucial link between the productive estuary and a relatively impoverished ocean. Menhaden constitute major food sources for a variety of coastal fishes and birds.

Gizzard (*Dorosoma cepedianum*) and threadfin (*Dorosoma petenense*) shads were also collected at SJ. Juvenile (young of the year) shads were taken in trawls in August and March. Adults of these commercially unimportant shads live in low salinity and freshwater habitats. However, the young are tolerant of higher salinities and are frequently taken in high marsh creeks and pools.

Anchovies are undoubtedly the most abundant schooling fishes in South Carolina estuaries. Two species occurred in trawl collections at both creeks. Because of their small size (<100 mm), neither species is effectively collected with the trawl. Adult bay anchovies (*Anchoa mitchilli*) were incidental catches in the trawl on every cruise. Striped anchovies (*Anchoa hepsetus*) did not occur from January through April. Larval and juvenile anchovies were collected with the epibenthic sled every month of the year. During the warm months, densities of anchovy eggs and larvae were very high in both sled and zooplankton collections.

Anchovies of all sizes are predators on planktonic and motile epibenthic crustaceans. Gut content analyses of small anchovies revealed the presence of large numbers of copepods. Mysids and decapod larvae were consumed by larger individuals. The diurnal movements and feeding habits of bay anchovies in a local intertidal creek are described by Reis and Dean (1981). Anchovies comprised a major portion of the diet of most large predators including bluefish, spotted seatrout, weakfish, and summer flounder.

Inshore lizardfishes (*Synodus foetens*) are regular but not common migrants to South Carolina estuaries during summer and fall. Individuals from 80-290 mm in total length occurred from July through November in trawl collections at both creeks. Some lizardfish larvae (31-36 mm) were taken in sled collections at both creeks in June. Spawning probably occurs in the spring in nearshore coastal waters. Adult lizardfishes remain partially buried in the substrate and attack small fishes and, occasionally, shrimps.

Two marine catfishes were collected in SJ Creek. The less abundant gafftopsail (*Bagre marinus*) (300 mm) was taken in gill nets in July. Sea catfishes (*Arius felis*) were common from June through September, but some small individuals were taken in trawls in January. Adults were often observed brooding their eggs in their mouths. Sea catfishes caught during the summer had penaeid shrimps, blue crabs, and fishes (e.g. menhaden, spot, American eel) in their guts.

Oyster toadfishes (*Opsanus tau*) are resident demersal fishes in temperate marsh creeks. Individuals from 20-290 mm occurred in trawls on all cruises except January. During the cold months, toadfishes become inactive and remain partially buried. More individuals were caught in the spring and summer when they were feeding on crabs near the creek bottom. Reproduction occurs in spring and summer. Eggs are attached to hard bottom materials and the emerging young resemble the adult.

Skilletfishes (*Gobiesox strumosus*) occupy the same habitat as the toadfishes, but this smaller species appears to be more abundant. A sucking disk on the underside of the fish allows it to camouflage itself from small crustacean prey which also live among oyster clusters and other obstructions. Small skilletfishes (<10 mm) were collected with the sled during most of the year, but adults were not susceptible to capture by the trawl.

The gadid family includes the familiar cold water groundfishes such as cod, but two species of hakes were collected at No Man's Friend and South Jones Creeks. Southern (*Urophycis floridanus*) and spotted (*U. regius*) hakes (50-140 mm) were taken in trawls from January through April. They were particularly abundant in SJ in April. Southern hakes were somewhat more common. These epibenthic predators consumed large numbers of mysids during the cold months. This observation is consistent with the feeding habits of hakes in Georgia estuaries (Sikora et al., 1972).

Striped cusk-eels (*Rissola marginata*) are peculiar fishes which spend the daylight hours buried, tail first, in the bottom. Cusk eels were usually caught at night while they were foraging on crustaceans near the bottom. Some individuals were taken at both creeks from September through April.

The killifishes are high marsh animals which rarely occur in major creeks. One sheepshead minnow (*Cyprinodon variegatus*) was collected in a January SJ Creek trawl. Young mummichogs (*Fundulus heteroclitus*) were taken in sled tows during July. Larval *Fundulus* which could not be identified to species occurred in summer sled collections. Killifishes play a major role in the trophic dynamics of the estuary, especially in marsh pools and creeks where they occur in very high densities.

Two species of silversides were incidental trawl catches in both creeks. Adults of both of these narrow fishes are less than 130 mm in total length and easily escape from the trawl net. During the warm months, large schools of Atlantic silversides (*Menidia menidia*) occur along creek banks and beaches. They tend to aggregate in deep channels when water temperatures are low. All trawl catches of silversides were between December and April. Larval rough silversides (*Membras martinica*) were collected in the epibenthic sled at SJ.

Dusky (*Syngnathus floridae*), northern (*S. fuscus*) and chain (*S. louisianae*) pipefishes were occasionally collected in both creeks. Because of their shape and size, no reasonable estimate of their abundance could be made with the trawl. Adults were taken from fall to spring. Juveniles occurred in sled collections during most of the year.

The sea basses were represented by two species in the creeks. Only one small rock sea bass (*Centropristes philadelphica*) was collected at NMF. A total of eight gag groupers (*Mycteroperca microlepis*) were taken at SJ from July through September. Both species were probably more abundant than trawl catches indicated, because basses usually remain hidden among bottom debris, and they are fast swimmers when disturbed. These creeks are ideal habitats for young basses and groupers which enter the high salinity marsh waterways as ocean spawned larvae each spring and summer. Gag grouper larvae were found in June sled samples.

Young bluefishes (*Pomatomus saltatrix*) were incidental trawl catches in spring and summer at both creeks. These fast swimming pelagic predators are common in estuaries during most of the year, but most migrate to the south along the coast in the winter. Adult bluefishes (260-360 mm) were frequently caught in gill nets from June through November. The population dynamics and distribution of bluefish in coastal waters was discussed by Kendall and Walford (1979).

One 86 mm juvenile cobia (*Rachycentron canadum*) was collected in a trawl at SJ in July. Cobia are most abundant in tropical waters, but individuals occur in South Carolina estuaries every year. In estuaries in the southern part of the state, adult cobia are seasonal migrants which support a popular sport fishery.

The carangids or jacks represent a large family of silvery fast swimming warm water fishes. Juvenile crevalle jacks (*Caranx hippos*), Atlantic bumpers (*Chloroscombros chrysurus*) and lookdowns (*Selene vomer*) were taken in trawls at both creeks between June and September. Jacks are not susceptible to capture by slow moving trawl nets, so juveniles may be quite common in high salinity areas. Seine collections in North Inlet creeks indicate that these and many other species of jacks are common in the area. Young jacks eat a variety of invertebrates, but fishes (e.g. anchovies, silversides) constitute the major dietary items.

Gray snappers (*Lutjanus griseus*) occurred in both creeks. One 55 mm juvenile was collected with the trawl in September, and 13-15 mm larvae were taken with the epibenthic sled in August. The larvae of this tropical fish probably originate from southern coastal spawning areas. Gray snappers are common in high salinity creeks in the summer. Numbers are caught in traps and seine hauls in North Inlet creeks each summer. Their habits are similar to those of the basses in that they remain close to bottom obstructions and feed on small epibenthic animals.

Three mojarras were collected during the study. Although Irish pompanos (*Diapterus olisthostomus*), spotfin mojarras (*Eucinostomus argenteus*) and silver jennies (*E. gula*) were not abundant, juveniles and small adults were taken in trawls in both creeks from August through November. Larvae occurred in sled samples in September and November. These small (less than 100 mm) silvery fishes feed near the bottom of major creeks, but appear to be more abundant in shallow high marsh creeks and pools during summer and fall.

Small pigfishes (*Orthopristis chrysoptera*) were collected in July and September. Larvae were taken with the sled in May and June at both creeks. Although pigfishes are common shallow water fishes in the tropics, relatively low numbers occur in South Carolina estuaries.

Two sparids or porgies, the sheepshead (*Archosargus probatocephalus*) and the pinfish (*Lagodon rhomboides*) were collected at both creeks. Young sheepsheads were caught in trawls in November, December and March and were most abundant at SJ. This popular gamefish is common around obstructions in estuaries and coastal waters. Larvae were caught in the sled in June at NMF. One large adult (536 mm) was caught in a gill net at SJ. Sheepsheads are year round residents which feed on molluscs, barnacles and a variety of invertebrates associated with encrusting benthic communities. Pinfishes were the eighth most abundant species in the trawl collections. None were caught in August, September and January; however, pinfishes are year-round residents of both marsh creeks. Larvae were very abundant in sled samples from December through March, Trawl caught individuals ranged from 25-180 mm in length.

The sciaenid or drum family includes many of the most familiar estuarine food and game fishes. Collectively, the sciaenids probably exceed all other groups of inshore fishes except anchovies and mullets in number and biomass (weight). Most species spawn near or in the ocean and larvae migrate to estuarine habitats where they remain for up to one year. Adults migrate to deeper and more southern areas during the winter. Most species are fast growing and live less than three years. Eleven species were caught in the study area and each is discussed below.

The silver perch (*Bairdiella chrysura*) does not grow large enough to be a sport or food species. It was the fourth most abundant fish in the trawl collections. Details of its seasonal and spatial distribution with respect to numbers and biomass are given in Tables 7-2 and 7-3. Young and adult silver perch were usually most abundant at SJ. They were most common from July through November; however, the largest collections were in March at SJ. Larvae were taken in sled samples from May through September. Silver perch are predators of epibenthic crustaceans and fishes.

Spotted seatrout (*Cynoscion nebulosus*) (winter trout) are important sport and commercial fishes in the Winyah Bay area, especially in the fall and winter. Adults (265-420 mm) were caught in gill nets in both

Table 7-2. Numbers of individuals of the eight most abundant fishes in trawl collections at NMF and SJ on all major cruises. Numbers are totals for all collections made during each cruise at each creek.

	AUG.		SEPT.		NOV.		DEC.		JAN.		MAR.		APR.		JUNE		JULY	
SPECIES	NMF	SJ	NMF	SJ	NMF	SJ	NMF	SJ	NMF	SJ	NMF	SJ	NMF	SJ	NMF	SJ	NMF	SJ
Brevoortia tyrannus	18	20	1	13	0	0	0	1	1	2	0	7	2	27	20	185	9	3
Anchoa mitchilli	568	2149	103	365	9	24	13	329	0	88	1	97	46	327	238	350	122	508
Bairdiella chrysura	16	58	17	18	5	40	1	12	0	2	0	179	3	8	2	0	0	16
Cynoscion regalis	26	36	0	9	0	1	0	0	0	0	0	0	0	0	3	35	51	45
Leiostomus xanthurus	837	528	42	340	31	185	15	11	0	12	158	505	198	309	175	248	351	299
Micropogonias undulatus	216	169	13	6	0	0	0	0	0	0	0	4	29	33	46	474	255	199
Trinectes maculatus	33	42	0	14	0	0	0	0	0	0	0	0	0	6	4	14	6	5
Symphurus plagiusa	12	20	19	25	20	9	3	19	0	5	4	4	1	10	5	3	4	5
All others	71	257	37	92	27	30	25	50	36	47	48	59	66	125	14	41	33	52
Total fishes	1797	3279	232	882	92	289	57	422	37	156	211	855	345	845	507	1350	831	1132

Table 7-3. Weight in grams of individuals of the eight most abundant fishes in trawl collections at NMF and SJ on all major cruises. Weights are totals for all collections made during each cruise at each creek.

	AUG.		SEPT.		NOV.		DEC.		JAN.		MAR.		APR.		JUNE		JULY	
SPECIES	NMF	SJ	NMF	SJ	NMF	SJ	NMF	SJ	NMF	SJ	NMF	SJ	NMF	SJ	NMF	SJ	NMF	SJ
Brevoortia tyrannus	730	893	39	458	0	0	0	8	11	15	0	77	17	657	658	2894	193	22
Anchoa mitchilli	464	2411	130	315	10	22	14	264	0	45	1	62	63	320	295	467	109	587
Bairdiella chrysura	271	612	296	307	114	1389	39	659	0	25	0	3831	79	242	17	0	0	64
Cynoscion regalis	463	486	0	95	0	16	0	0	0	0	0	0	0	0	34	24	407	264
Leiostomus xanthurus	9103	7587	768	5568	526	2987	266	212	0	117	1789	10612	1119	6966	2098	3745	2748	2869
Micropogonias undulatus	4130	3271	401	107	0	0	0	0	0	0	0	169	581	750	1003	1678	2238	2270
Trinectes maculatus	272	470	0	259	0	0	0	0	0	0	0	0	0	14	13	70	43	43
Symphurus plagiusa	51	130	129	199	203	86	5	78	0	23	17	11	2	48	25	11	24	29
All others	2319	4381	782	2447	465	1838	130	578	142	225	383	1132	1489	2651	305	3348	294	1262
Total fishes	18074	20241	2545	9755	1318	6322	454	1799	153	1024	2190	15864	3350	11648	4447	12237	6056	7410

creeks in September and November. In September, some females which had recently released their eggs were collected. Juveniles (<130 mm) were incidental catches in trawls during most of the year. Larvae occurred in sled collections in June and September in both creeks. Spotted seatrout are dependent on estuaries as nursery grounds for the young and adults do not make coastwide migrations like most other gamefishes. Trawl records for seatrouts in other South Carolina estuaries are given in Lunz and Schwartz (1970). Penaeid shrimps were most commonly found in the guts of gill net caught seatrout.

The weakfish (*Cynoscion regalis*) (summer trout) is a close relative of the spotted seatrout. Adults were common in summer and early fall, and juveniles were abundant in trawls from June through November. Despite its being a fast swimmer, the weakfish was the sixth most abundant species in the trawl study (Table 7-2). Epibenthic sled collections produced larvae from May through September. Weakfishes are caught by local anglers and considered a fine food and sport fish. It is a major commercial species in northern estuaries. Foods include shrimps and small fishes.

The spot (*Leiostomus xanthurus*) is one of the dominant fishes in east and Gulf coast estuaries. In this study, spot ranked second to anchovies in terms of numbers of individuals (Table 7-2) and exceeded all other species in weight on every cruise (Table 7-3). On many tows, hundreds of juvenile spot were collected, and one SJ collection yielded more than 700 individuals. Spot were most abundant from March through September, and, although winter densities were low, spot were only absent in January at NMF.

Adult spot spawn in the ocean in the late fall, and the migration of high densities of larvae into the estuary each winter is very distinct. Larvae from 11-15 mm in total length first occurred in sled samples in January, and at least a few were collected in almost every sled tow at both creeks through June.

The length frequency analysis for spot catches on all cruises is illustrated in Fig. 7-6. Most individuals collected from August through November (80-130 mm total length) were spawned the previous fall. Young of the year larvae were not retained by the trawl in January collections, and their presence was not detected in trawl samples until they were more than 20 mm in length in March. Most of these young were in the 30-70 mm range in June and 60-100 mm range in July. The presence of 100-140 mm individuals from March to June is probably due to the greater susceptibility to capture of fishes of this size relative to larger individuals. Large spot avoid trawl nets and appear to occupy flat bottoms in Winyah Bay and shallow ocean areas instead of marsh creeks.

Dawson (1958) gives a thorough account of the life history and ecology of the spot. More recent studies by Chao and Musick (1977), Weinstein (1979), Hodson et al.(1981) and Weinstein and Walters (1981) have greatly contributed to our understanding of this important species.

Three species of kingfish or whiting were collected at SJ. Adult northern (*Menticirrhus saxatilis*), southern (*M. americana*), and Gulf (*M. littoralis*) whiting were caught in gill nets in the summer and fall. Juvenile whiting (less than 150 mm) were incidental in trawl catches at the same time. Larval southern kingfish occurred in sled collections

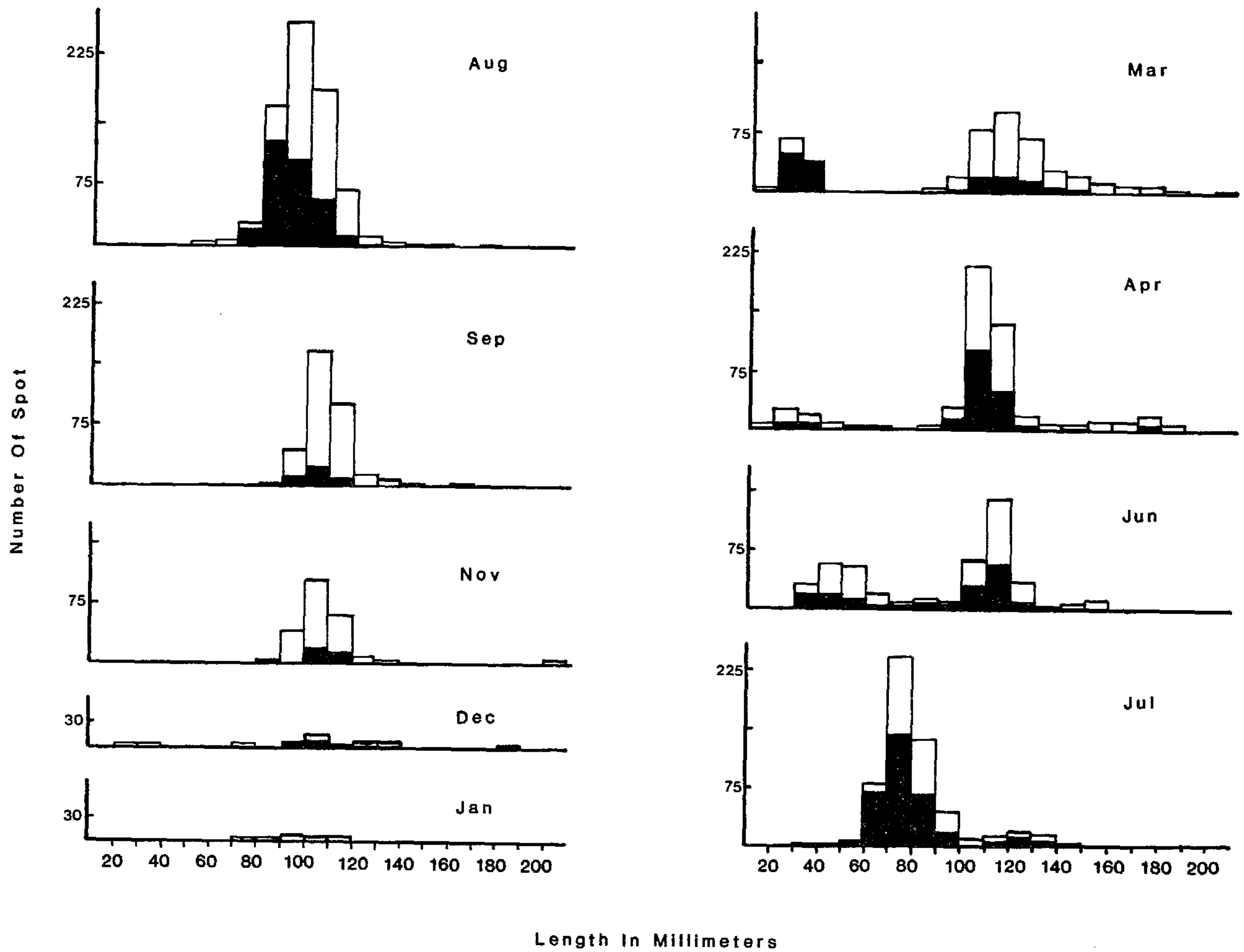


Figure 7-6. Length frequency analysis of spot (*Leiostomus xanthurus*) in trawl collections on major cruises at NMF and SJ. Height of each bar indicates total number of spot of that size class at both creeks. Shaded portion of each bar represents number collected at NMF.

in June and August at SJ. All three species are most common in high salinity areas, especially along beaches where they are caught by anglers. Whiting species are difficult to distinguish from one another. Bearden (1963) reported that southern kingfish were the most common of the three species in subtidal estuarine areas in South Carolina.

The Atlantic croaker (*Micropogonias undulatus*) was the third most abundant fish in both creeks. More than 1400 juvenile and small adult croakers were collected from March through September (Table 7-2). This popular sport and food fish was represented by larvae and small juveniles in the sled samples on every cruise except May and July. Large adults are not common in this section of the croaker's long geographical range, but South Carolina estuaries are very important nursery areas for this species.

The length frequency analysis for all croaker collected with the trawl is given in Fig. 7-7. Large numbers of 110-140 mm fishes were present in August, but most left the area before the September cruise. Two year classes were recognized in April and June when the creeks were repopulated by a migrating population. Young of the year which spawned in the ocean in the fall and winter were first apparent as 30-50 mm juveniles in the June trawls. Bearden (1964) suggests that smaller fish occur in low salinity areas and that an average length of 150 mm is typical for a one year old fish.

Juvenile black drum (*Pogonias chromis*) (<150 mm) were collected in August and September. Little is known about the spawning and distribution of this species in the Winyah Bay area. Small adults are often

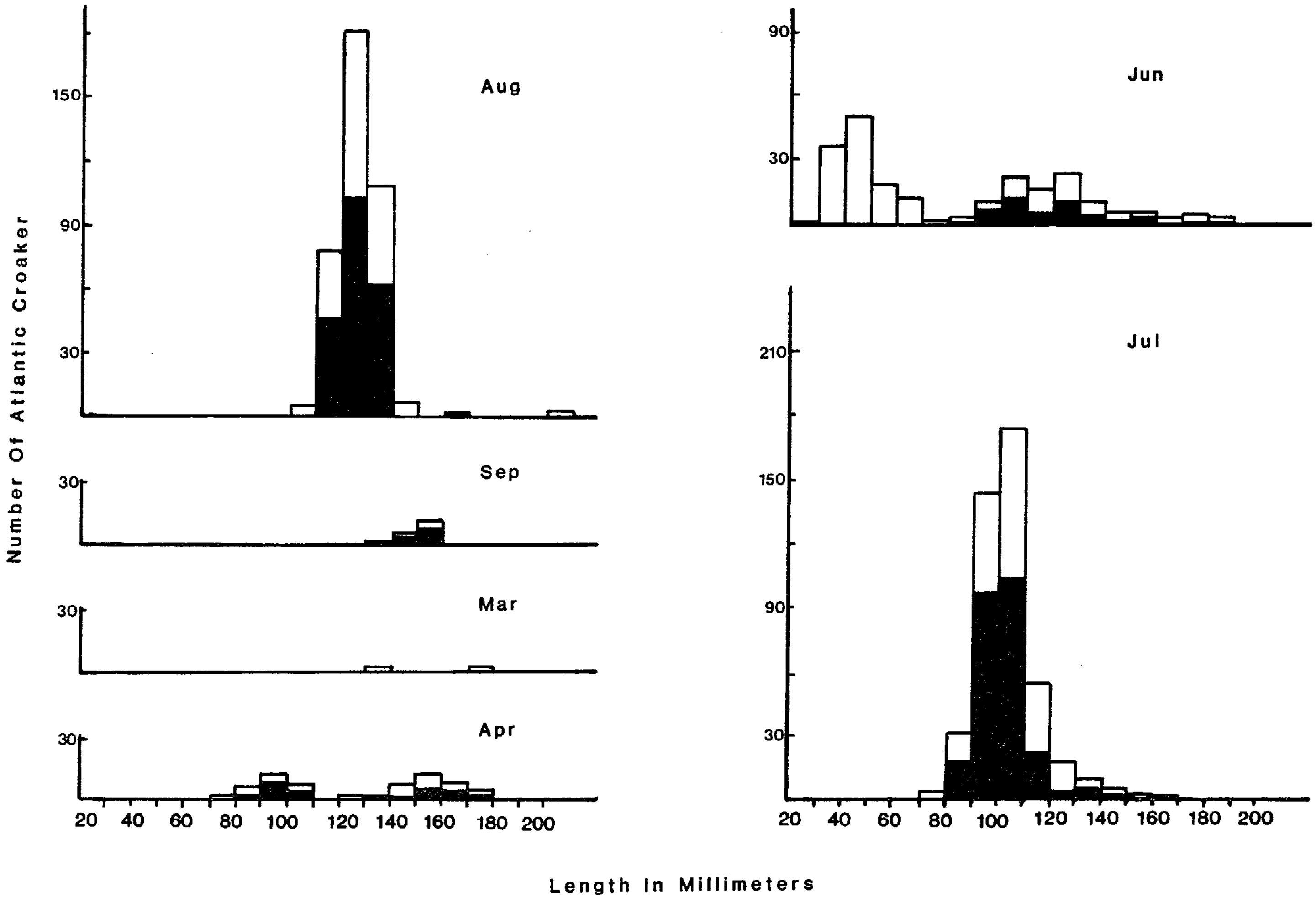


Figure 7-7. Length frequency analysis of Atlantic croaker (*Micropogonias undulatus*) in trawl collections on major cruises at NMF and SJ. Height of each bar indicates total number of croaker of that size class at both creeks. Shaded portion of each bar represents number collected at NMF.

caught around obstructions by anglers seeking sheepshead.

Red drum (*Sciaenops ocellata*) (spot tail or channel bass) are one of the most popular gamefishes in the southeast and Gulf states. Although adults from 1 to 50 pounds in weight are caught in the surf and in certain marsh creeks, none were collected in gill nets or trawls. Juveniles (< 100 mm) were taken in November, January and March. Larvae (4-10 mm) occurred in sled samples from August through October. Red drum are year-round residents of the high salinity marshes. Young eat a variety of crustaceans and fishes. The guts of adults caught along marsh banks usually contain fiddler crabs.

The star drum (*Stellifer lanceolatus*) is a small, little-known sciaenid of temperate and subtropical estuaries. Sled collections in both creeks in early summer yielded 3-4 mm larvae and, although these early life stages were also present in August, some small juveniles (<40 mm) were collected. No star drum were caught in trawls at either creek.

Spadefishes (*Chaetodipterus faber*) were collected in August, September, and November at both creeks. They were most abundant in August when most individuals were 30-70 mm in total length. Juvenile spadefishes are common in high salinity areas during the summer after migrating from remote spawning areas. No larvae were collected with the sled.

Two species of mullet were abundant in the creeks. Schools of white mullet (*Mugil cephalus*) juveniles and adults are ubiquitous in the Winyah Bay area. These fast swimming schooling fishes occur with menhaden in the surface waters, especially from spring through fall. Some juveniles (<100 mm) were incidental catches in trawls from July through September. Adults are caught in seines and gill nets during this period. Striped mullet (*Mugil cephalus*) are less common; some juveniles occurred in November and December. Ovigerous female adults of both species were taken in the fall and small juveniles occurred in sled samples in January. Large schools of small juveniles (<30 mm) were observed swimming near the surface under lights in winter and spring. Anderson (1957 and 1958) described the early life history and distribution of both species on the southeast coast.

Mullet feed on organic particles and small invertebrates (Collins, 1981). They are widely distributed in estuaries and appear to be very tolerant of temperature and salinity fluctuations. From an energy standpoint, they are important assimilators of marsh production which is not utilized by other large organisms. Mullets are major food sources for predators such as gars, spotted seatrouts, bluefishes and flounders.

Feather blennies (*Hypsoblennius hentzi*) (20-80 mm) were collected in trawl nets in November and January. Larvae were taken in October and June. The only other blenny collected was the striped blenny (*Chasmodes bosquianius*) which occurred as larvae in August sled samples. Both species are abundant in the creeks and throughout the high salinity coastal areas, but their cryptic benthic life styles and small sizes prevent them from being caught in trawls. Blennies are predators of small crustaceans and other invertebrates.

Gobies are even more abundant on creek bottoms than blennies. Darter, sharptail, freshwater, naked, seaboard, clown and green goby larvae and small juveniles were identified in sled collections, but only a few adult naked (*Gobiosoma bosci*) and a single sharptail (*Gobionellus nastatus*) adult were taken with the trawl. Since none of the seven species is trawl susceptible, assessments of their relative abundance were not possible. However, the abundance of larvae from June through October indicated that large numbers of these year-round residents were present. Gobies inhabit irregular shell and debris-laden bottoms and were much more common in SJ than NMF.

A single 140 mm juvenile spanish mackerel (*Scomberomorus maculatus*) was taken in a trawl at SJ on the August cruise. This common gamefish was probably a stray visitor from adjacent ocean waters, although the presence of numbers of small mackerel in the estuary could not be detected with trawls or gill nets.

One juvenile harvestfish (*Peprilus alepidotus*) and one juvenile butterfish (*Peprilus triacanthus*) were collected in August trawls at SJ. These fast-swimming pelagic fishes utilize high salinity estuarine areas as nursery grounds. Small individuals migrate from ocean spawning grounds in the summer.

Juvenile bighead searobins (*Prionotus tribulus*) occurred from January through June. Greatest numbers were taken at both creeks in May when 40-80 mm juveniles were present. Larvae were collected with the sled in April, June and August. Other species of searobins are common in North Inlet creeks during the summer.

Seven species of flatfishes representing three families occurred in trawl collections. Juvenile ocellated flounders (*Ancyclopsetta quadrocellata*) were caught in trawls from March through June. Ocellated flounder larvae were not collected with the sled. Juveniles and small adult bay whiffs (*Citharichthys spilopterus*) occurred from July through December, and larvae were taken in sled tows in December and March. Fringed flounders (*Etropus crossotus*) were common at both creeks from June through December, and larvae were taken in sled tows in December and March. Flounders less than 40 mm in total length were not susceptible to capture with the trawls, and it is likely that fringed and other small flounders were much more abundant than the trawl data indicated.

The summer (*Paralichthys dentatus*) and southern (*P. lethostigma*) flounders are favorite sport and commercial species in coastal waters. The two species are difficult for fishermen to separate, but the southern flounder was much more abundant than the summer flounder in the study area. Young flounders (<180 mm) were collected with the trawl on all but the August cruise. Southern flounders were most abundant from December through March. A few summer flounder juveniles were taken in spring and fall. The adults of both species migrate to deep ocean spawning grounds in the fall. Larvae of both species arrive in the estuary in December, and were caught in sled samples at both creeks until May. Young summer and southern flounders inhabit brackish and high salinity areas where they prey on crustaceans and fishes. Adults migrate back to inshore waters in the spring and remain until fall. The inshore distribution of paralichthid flounders in North Carolina estuaries is discussed by Powell and Schwartz (1977). Southern flounder were the more abundant of the two species in gill net catches from June through September.

Hogchokers (*Trinectes maculatus*) were the second most abundant flatfishes in the collections. These medium size flounders occurred from April through September and were particularly abundant in August (Table 7-2). They were usually more common at SJ and, although large numbers occurred at SJ in September, none occurred at NMF on that cruise. Hogchoker larvae were taken with the sled from June through August. Hogchokers occur on mud and sand bottoms from the ocean to freshwater extremes of South Carolina estuaries. They consume polychaete worms and soft-bodied invertebrates. Hogchokers have no commercial value and have not been found in the guts of any other fishes.

Blackcheek tonguefishes (*Symphurus plagiusa*) were the most abundant flatfishes and the seventh most abundant species in the creeks (Table 7-2). Juvenile and small adult tonguefishes (20 - 90 mm) were collected on every cruise, but were most abundant from August through November. Larvae and small juveniles occurred in sled collections in all months except February, April, May and June. Small tonguefishes are common throughout the surrounding area during the warm months. They are not effectively sampled with a trawl.

One juvenile (17 mm) planehead filefish *(Monacanthus hispidus)* was collected in a November SJ collection. Juvenile filefishes migrate from tropical spawning areas in the summer, and in some years are abundant in South Carolina estuaries.

Larval northern puffers (*Sphoeroides maculatus*) (10 - 12 mm) were collected in the sled at NMF in June and August. Young puffers take up residence in high salinity areas after migrating from ocean spawning grounds. Adult puffers were not collected in the trawl study and appear to be rare in the Winyah Bay area.

B. FISH COMMUNITIES

The otter trawl is one of the most widely used net designs for capturing fishes in subtidal areas, but it is inadequate for the collection of the majority of species which inhabit estuarine waters. Seines, gill nets, beam trawls, and sleds also have limited applications in the characterization of the fish fauna. Collections made with nets never provide accurate measures of the abundance of any species; however, valuable information on community composition and population structure (e.g. length frequency) can be obtained. Since there are few practical alternative methods of quantifying fishes which yield more accurate information, studies which utilize a particular gear at regular intervals at specific locations must be relied upon to provide the information. Consistency in sampling is necessary. Relative abundance data are used to determine temporal variation for some species and, to a lesser extent, to describe species diversity.

In the trawl study at NMF and SJ Creeks, 65 species of fishes were taken in 41 trawl tows on 9 cruises. More than 13,300 fishes were identified to species and most of them were measured and weighed. The eight most abundant species accounted for 92% of the total number of fishes collected in the trawl study (Table 7-2). These eight species also accounted for 81% of the total weight (biomass) of all fishes caught in the program (Table 7-3). Figure 7-8 shows the total number of fishes collected on each cruise. Maximum numbers at both creeks occurred in

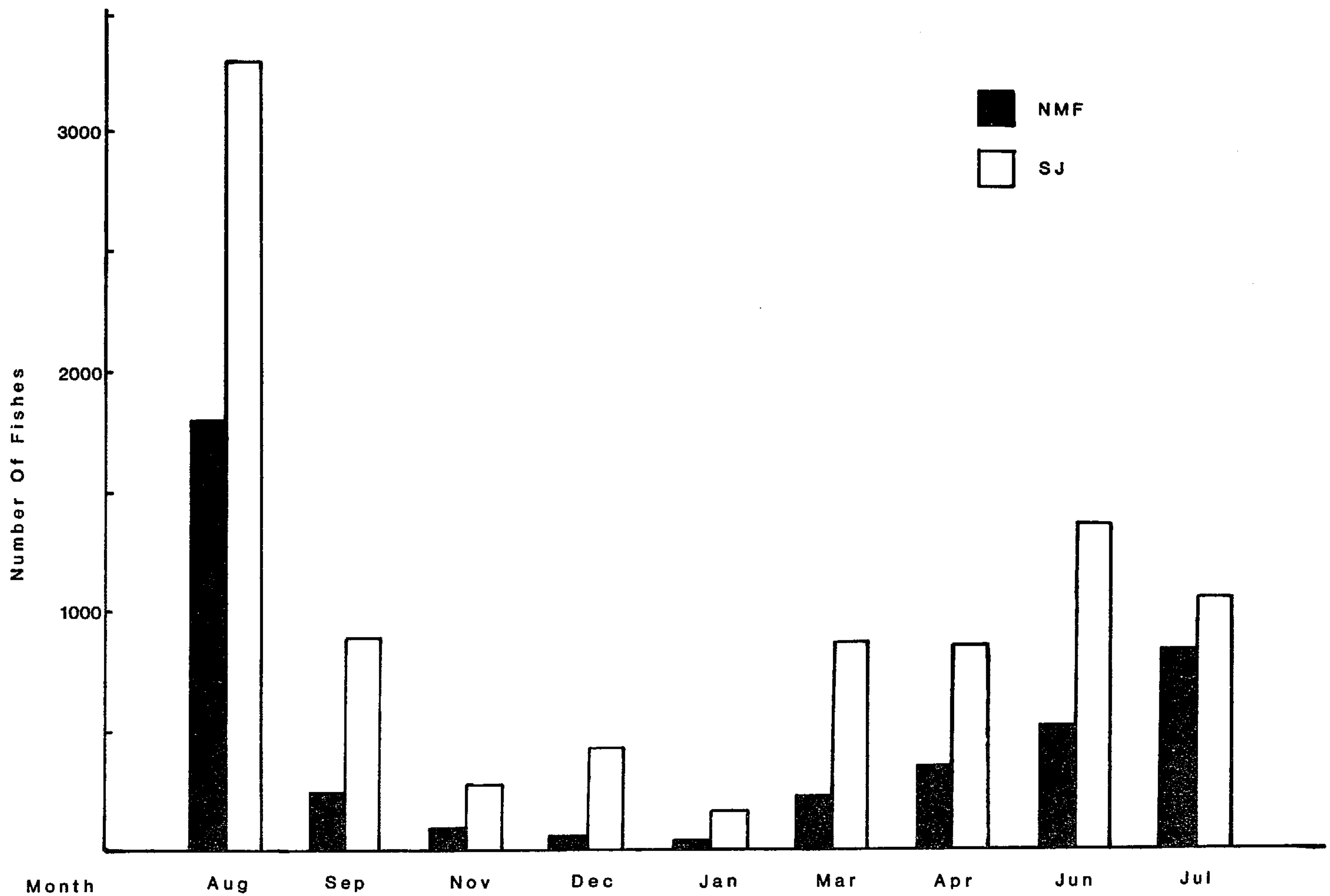


Figure 7-8. Total numbers of all fishes in trawl collections on major cruises. First column of each couplet indicates numbers for NMF, second column for SJ.

August. Fish abundance decreased in September and November, remained low through January, increased abruptly in March, and continued to increase slightly through July. A similar pattern was observed for total weight of all fishes collected on each cruise (Fig. 7-9). The abrupt increase in fish weight in March indicates that the fishes which were in SJ in March were larger than those present in January. The fishes in NMF in August were larger than those in SJ.

One way to examine changes in the composition of fish communities is to use diversity indices. The three indices used to analyze the trawl data are described in Table 7-4 and the results of the analyses are in Table 7-5.

At NMF, all three indices showed that diversity increased from August to an annual peak in November from which it declined to the annual low in January (Table 7-5). Diversity increased in March and April, decreased slightly in June and reached August value levels in July. In summary, despite relatively low total numbers of fishes at NMF in November, a large number of species were represented. Many warm water migratory species occurred in the marsh creeks in the fall.

The three diversity indices followed a different seasonal pattern at SJ Creek (Table 7-5). While the species richness values were at the annual maximum in September, the evenness index was at one of the lowest values of the year. All indices decreased in December. Large increases were seen in J and H' in January and, after a slight decrease in March, levels returned to January levels through July.

In general, values for the diversity indices at NMF and SJ were high-

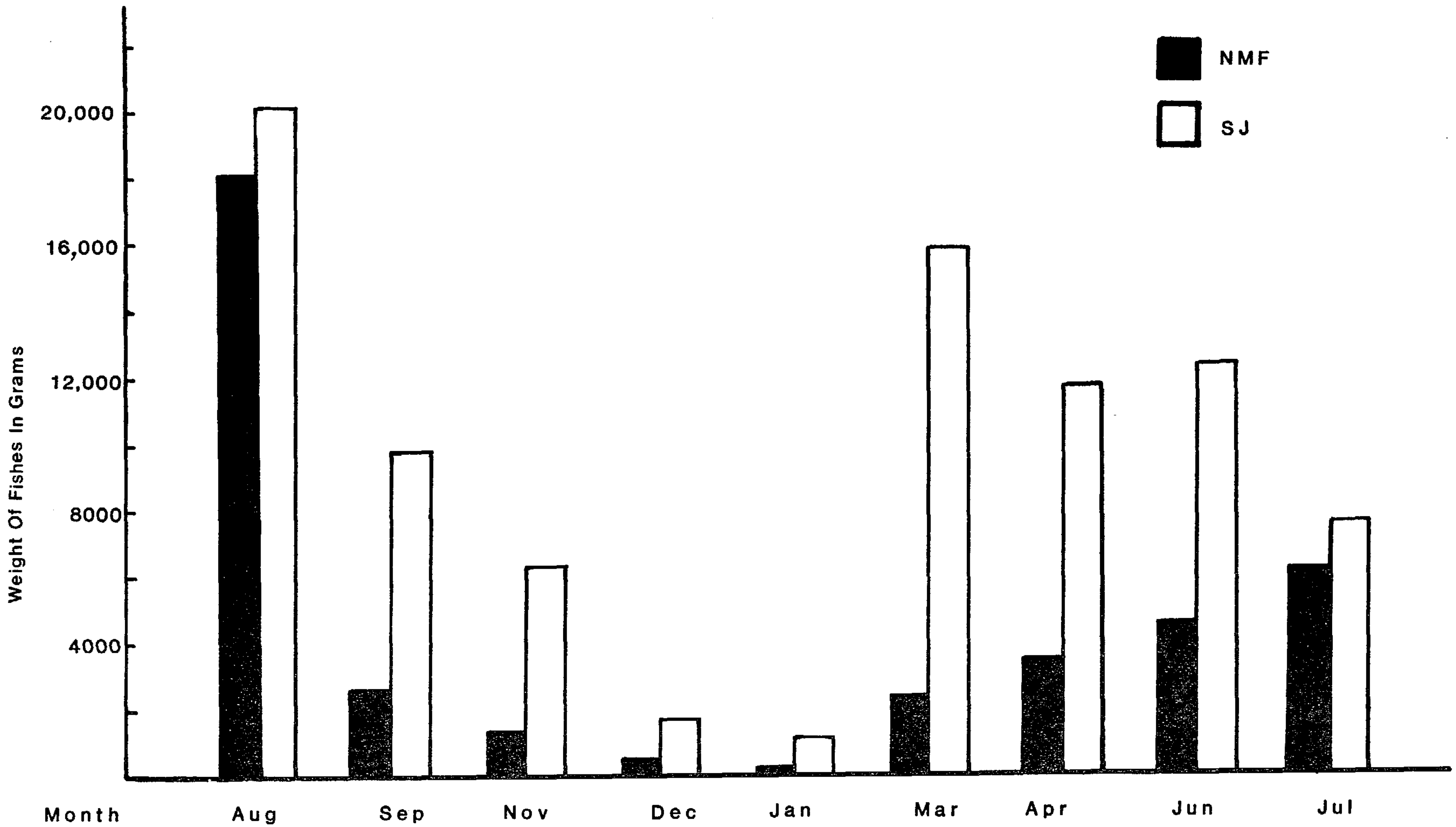


Figure 7-9. Total weights of all fishes in trawl collections on major cruises. First column of each couplet indicates numbers for NMF, second column for SJ.

Table 7-4. Diversity indices used for fish community analysis.

1. Species richness component (Margalef, 1968 and Dahlberg and Odum, 1970)

   $D = (S-1)/\log_e Nm$ where S = number of species and N = number of individuals

2. Shannon-Weaver function (Bechtel and Copeland, 1970, and Dahlberg and Odum, 1970)

   $H' = -\Sigma P_i \log_e P_i$, where P_i is the proportion of individuals in the i^{th} species

3. Evenness index (Pielou, 1966)

   $J = H'/\log_e S$

Table 7-5 . Values for fish diversity indices at NMF and SJ Creeks. Abbreviations are: S = number of species; N = number of individuals; D = species richness index; H'= Shannon-Weaver function; and J = evenness index.

No Man's Friend Creek

MONTH	S	N	D	H'	J
Aug	19	1797	5.53	0.62	0.49
Sep	16	232	6.34	0.79	0.66
Nov	15	92	7.13	0.90	0.77
Dec	10	57	5.13	0.76	0.76
Jan	6	37	3.19	0.33	0.43
Mar	14	211	5.59	0.47	0.41
Apr	17	345	6.31	0.67	0.55
Jun	17	507	5.92	0.59	0.48
Jul	17	831	5.48	0.65	0.53

South Jones Creek

MONTH	S	N	D	H'	J
Aug	34	3280	9.39	0.64	0.42
Sep	30	882	9.85	0.71	0.48
Nov	19	289	7.31	0.60	0.47
Dec	16	422	5.71	0.44	0.36
Jan	16	156	6.84	0.75	0.62
Mar	16	855	5.12	0.56	0.46
Apr	17	845	5.47	0.72	0.58
Jun	17	1350	5.11	0.70	0.57
Jul	21	1132	6.55	0.66	0.50

er than those reported for other salt marsh creeks (Cain and Dean, 1976; Subrahmanyam and Coultas, 1980).

A comparison of NMF and SJ Creeks indicated that maximum diversity occurred earlier in the fall at SJ and that diversity was somewhat greater at SJ than NMF. The most striking difference between the two creeks was the much greater values for all three indices at SJ in January (Table 7-5). Small sample size such as the low total number values for January is known to affect the calculation of various indices (Pielou, 1977).

Declines in diversity between the fall maximum and winter minimum are related to the migration of many warm water species from the estuary. Similar decreases were observed for the fish fauna of an intertidal creek in North Inlet (Cain and Dean, 1976) and Winyah Bay (Wenner et al., 1980).

At least 33 of the 85 species collected with all gear at NMF and SJ are year-round residents of the creeks and adjacent high salinity areas. The majority of the migratory species arrived in the summer and fall, although some (e.g., the hakes) entered shallow creeks in the winter.

The total numbers and weights of fishes at SJ were always greater than those at NMF (Fig. 7-8 and 7-9). This pattern is consistent for all of the most abundant species of fishes. Bay anchovies were 3.9 times and pinfish were 4.2 times more abundant at SJ. Silver perch, spot, menhaden, croakers, southern flounders, tonguefishes, hogchokers, and spotted seatrout were also more abundant at SJ. Of the 65 species caught in the trawl, only silversides, bighead searobins and cusk eels were more common at NMF than SJ Creek. Only 4 species were collected exclusively at NMF, while 23 species occurred only at SJ. Fishes which were collected at SJ only were either more typical of ocean habitats (e.g., cobia, whitings, butterfishes, harvestfishes, and Spanish mackerel) or more common on irregular subtidal habitats (e.g. eels, blennies, gobies, groupers and snappers). Despite the high and roughly equivalent salinities at both creeks on all cruises, the closer proximity of SJ to the ocean indicates a closer association than NMF to the sea. Additionally, the more complex bathymetry and well developed sessile benthic communities at SJ provide a greater number of habitats for fishes and their prey.

The results of the trawl study in NMF and SJ can be compared to other trawl surveys in South Carolina estuaries. A 12-month survey near Prince Inlet yielded 67 species (Bears Bluff Labs, 1965). Spot, croakers, hogchokers, tonguefishes, and flounders accounted for the largest portion of the catch. One major difference between the two studies is the occurrence of the star drum as a major species at Prince Inlet.

Sandifer et al. (1980) summarized the results of studies conducted by South Carolina Marine Resources Research Institute (Charleston) in several estuaries from 1975-1978. In a trawl survey of the nearby Santee Estuary, a record number of species (77) were collected. Low salinity areas were sampled and white catfishes comprised a major part of the catch. High salinity species assemblages were similar to those at NMF and SJ.

Shealy et al.(1974) reported that 88 species of fishes were caught in trawls at 33 stations in estuaries from Winyah Bay to Caliboque Sound. All stations were sampled at least quarterly for 12 months. Croaker and spot dominated most collections.

Wenner et al. (1980) conducted monthly trawls at nine stations in Winyah Bay from January 1977 to December 1978. Stations were located in the channel from the lower bay lighthouse to the freshwater reaches of all four rivers feeding the estuary. A total of 77 species of fishes were collected in 216 collections. The dimensions of the trawl and its net size were larger than the device used in the NMF-SJ study; however, similar seasonal changes in fish diversity were observed. Other similarities in the results of the two studies include the dominance of juvenile fishes at all stations and the importance of relatively few species. In Winyah Bay, seven species comprised more than 90% of the total numbers. Among the high salinity species, all but the star drum were also dominants at NMF and SJ. In fact, the star drum was the most abundant fish in the Winyah Bay study. It is not known whether the major difference in the abundance of star drum in the two studies is related to year to year fluctuations in population sizes or to the general distribution of the species within the estuary. Several other species which were fairly common in Winyah Bay were not collected at NMF and SJ; these include the black sea bass, Atlantic thread herring, banded drum, windowpane and striped bass. Commercial gill nets set in Mud Bay catch large numbers of small adult striped bass, red drum, and, when salinities are depressed by high river discharges, yellow bullheads. Young Atlantic and shortnose sturgeons also regularly occur in gill net sets in Mud Bay adjacent to NMF and SJ, but none were collected in this study.

In summary, NMF and SJ are populated by large numbers of finfishes, most of which are juveniles. The diversity and abundance of fishes, especially during the summer, indicates that these creeks are very important nursery areas for coastal species. Almost all of the species which are of commercial and recreational significance in South Carolina occurred at the creeks. The majority of these species were represented by postlarval or young juveniles which had migrated from remote spawning locations to marsh creek habitats which provided rich food supplies and shelter from larger predators.

CHAPTER 8. REPTILES, BIRDS AND MAMMALS

Reptiles, birds, and mammals were not censused or collected in the NMF or SJ areas, yet they constitute major components of the salt marsh and estuarine ecosystems. Observations on the occurrence of the various species are reported in this chapter. More complete information on the distribution and abundance of these animals is found in Sandifer et al. (1980).

Only one reptile, the diamondback terrapin was common in the creeks during the study. The race recognized in South Carolina waters is known as *Malaclemys terrapin centrata*. This turtle is one of the world's few estuarine reptiles, since it completes its entire life cycle in brackish and high salinity marsh areas. Coker (1906) observed that diamondback terrapins could live in freshwater for long periods, but they are most abundant in the lower estuaries.

According to Hildebrand (1932), terrapins may reach sexual maturity at six years of age and live for more than 40 years. Females move to sandy high marsh and beach areas to deposit eggs in shallow nests. In North Carolina marshes, young turtles hatch in about eight weeks (Hay, 1917).

Diamondback terrapins feed on or near the marsh surface where they consume fiddler crabs (*Uca* spp.) and snails (*Littorina* spp. and *Melampus* spp.). Hurd et al. (1979) reported on the feeding behavior and aspects of the biology of the terrapin in Delaware marshes.

Terrapins were observed in the creeks from April through November, but no evidence of their presence was found during the coldest months. In the northern section of their coastwide range, terrapins hibernate in the mud along creek banks (Yearicks et al., 1981). Although hibernating terrapins have not been found in the study area, it is likely that they become dormant during the winter. Huge numbers of terrapins abruptly appear in the creeks each spring.

Other turtles occur in Winyah Bay, NMF, and SJ from spring through fall, but they are not common. The loggerhead, green and Kemp's Ridley sea turtles occur seasonally in South Carolina coastal waters. Leatherbacks and hawksbills have been taken in offshore waters, but are much rarer. Dead turtles are often washed into the surf at North and Debidue Islands, and loggerhead and juvenile green turtles have been observed and collected from North Inlet creeks (Talbert, personal communication). Sea turtles may use estuarine areas for feeding grounds more frequently than casual observations may indicate.

Loggerhead turtles (*Caretta caretta*) were seen in NMF and SJ in the summer and fall, and are known to nest on beaches bordering lower Winyah Bay (Stancyk, Talbert, and Miller, 1979). Nesting is especially dense on the oceanward beaches of the islands adjacent to Winyah Bay (North Island, Sand Island, South Island). Nesting also occurs on the parts of those islands forming the mouth of the bay, as well as on the sand beach of South Island within the bay. Loggerheads occur throughout the warm months in both Winyah Bay and the tidal creeks. Juveniles, which feed on bottom invertebrates, are especially abundant. Adults may occupy large bays between nestings, and have entered Winyah and Romain Bays while being radiotracked (S. Hopkins and T. Murphy, personal communication).

The American alligator (*Alligator mississippiensis*) occasionally occurs in high salinity estuarine waters, but are more common in old ricefields and freshwater marshes. Alligators have been observed in No Man's Friend Creek and along the edges of Mud Bay marshes. Nesting occurs on higher ground. Alligators become dormant during the coldest months. In South Carolina, alligators are protected by special regulations (Sandifer et al., 1980).

At least five species of snakes are known to occur in estuarine marshes and waterways. The eastern cottonmouth (*Agkistrodon piscivorous*), canebrake rattlesnake (*Crotalus horridus*), and three species of water snakes, (*Natrix* spp.) are primarily freshwater marsh and swamp inhabitants, but are known to wander in brackish and salt marsh areas. None were observed at NMF, SJ or Winyah Bay during this study.

Birds are, of course, the most conspicuous and abundant higher animals occurring in the study area. Numbers, species composition, and space use patterns are not well documented; however, a considerable amount of reliable and useful information has been gathered by Baruch Institute researchers (R. Christy, P. DeCoursey, K. Bildstein, and P. Frederick) and S.C. Wildlife, and Wildlife and Marine Resources Department personnel (J. Cely and P. Wilkinson). Sandifer et al. (1980) provides a summary of the literature pertaining to South Carolina coastal birds.

Christy, Bildstein, and DeCoursey (1981) reported bird census figures for the NMF and SJ areas based on biweekly surveys with an airplane from August 1978 to September 1980. Information on the birds on the huge Pumpkinseed Island rookery adjacent to SJ Creek (Fig. 1-1) has been collected since 1974 by some investigators. This relatively large isolated nesting ground for colonial wading birds supports up to 44,000 individuals at the peak of the nesting season.

A checklist of birds known to occur in the creeks and marshes of the study area is given in Table 8-1. From spring to fall many species of shorebirds feed on the vast intertidal mud flats which surround Mud Bay, while other species of water birds dive after fishes and macroinvertebrates.

Large numbers of ducks feed and raft in the relatively undisturbed Mud Bay area, especially during the winter. The majority of water birds using the study area are migratory forms, but many resident species occur.

The eastern brown pelican (*Pelicanus occidentalis*) is one of the most frequently sighted birds in the study area. Individuals or small flocks of pelicans feed from the brackish portion of Winyah Bay to many miles off the coast during most of the year. Often groups of hundreds of birds can be seen standing on sandy shores. During our sampling cruises, pelicans fed on schools of mullet and menhaden in the creeks. The eastern brown pelican is an endangered species in South Carolina and the nation, and the population on this part of the coast is one of the largest surviving (Sandifer et al., 1980).

The American peregrine falcon (*Falco peregrinus*) also has endangered status on the state and federal lists. There have been confirmed sightings of this seasonal migrant by Baruch Institute personnel on North Island, North Jones Creek, and Goat Island in the North Inlet area on several occasions.

The southern bald eagle (*Heliaeetus leucocephalus*) is another endangered bird which is commonly sighted in the study area. An active nest of this resident fish-eating bird of prey is located on the Thomas Yawkey Wildlife Center on the south shore of Winyah Bay, and juveniles have been observed feeding in the channel near our Esterville Plantation station (T. Murphy, personnel communication).

Raccoons (*Procyon lotor solutus*) are common around marsh creeks which are adjacent to terrestrial areas. At NMF raccoons were observed swimming in the creek and feeding on crabs and mussels (clams) on the marsh surface. Raccoons probably use marshes for feeding grounds only, since nesting usually occurs in trees. Aspects of the ecology of raccoons in South Carolina estuaries are summarized by Sandifer et al. (1980).

River otters (*Lutra canadensis lataxina*) were observed in NMF in August. These mammals are more aquatic than raccoons and Wilson (1954) suggests that they are carnivorous animals which are more dependent on fishes and swimming crabs than other marsh animals.

The occurrence of rabbits, voles, deer, and rice rats on estuarine marshes are discussed by Sandifer et al. (1980).

The Atlantic bottle-nosed dolphin (*Tursiops truncatus*) or porpoise, was commonly observed in NMF and SJ. Johnson et al. (1974) and Sanders (1978) claim that this porpoise is the only resident marine mammal in

South Carolina waters. Porpoises are usually seen in small groups throughout North Inlet and Winyah Bay year-round. Individuals are sometimes observed leaving the water to slide onto the marsh surface, presumably to catch an emergent turtle, crab, or fish.

Table 8-1. Checklist of birds known to use Mud Bay and surrounding creeks and marshes.

Common Loon
Red-throated Loon
Red-necked Grebe
Horned Grebe
Brown Pelican
Double-crested Cormorant
Great Blue Heron
Green Heron
Little Blue Heron
Cattle Egret
Great Egret
Snowy Egret
Louisiana Heron
Black-crowned Heron
Yellow-crowned Heron
Least Bittern
Wood Stork
Glossy Ibis
White Ibis
Mallard
Black Duck
Gadwall
Common Pintail
American Widgeon
Redhead
Canvasback
Scaup
Common Goldeneye
Bufflehead
Ruddy Duck
Red-breasted Merganser
Hooded Merganser
Turkey Vulture
Black Vulture
Red-tailed Hawk
Bald Eagle
Northern Harrier
Osprey
Peregrine Falcon
Merlin
American Kestral
Clapper Rail
Virginia Rail
Sora
Common Gallinule
American Coot
American Oystercatcher
American Avocet
Semipalmated Plover
Black-bellied Plover
Marbled Godwit
Whimbrel
Yellowlegs
Willet
Spotted Sandpiper
Ruddy Turnstone
Dowitcher
Semipalmated Sandpiper
Western Sandpiper
Least Sandpiper
Dunlin
Herring Gull
Ring-billed Gull
Laughing Gull
Bonaparte's Gull
Gull-billed Tern
Forster's Tern
Common Tern
Little Tern
Royal Tern
Sandwich Tern
Caspian Tern
Black Tern
Black Skimmer
Barred Owl
Short-earred Owl
Common Nighthawk
Belted Kingfisher
Tree Swallow
Rough-winged Swallow
Barn Swallow
Fish Crow
Marsh Wren
Red-winged Blackbird
Boat-tailed Grackle

CHAPTER 9. WINYAH BAY: 1980-81 CRUISES

Although the primary thrust of the research discussed in this report was to quantify physical and biological aspects of the exchange areas between Winyah Bay and North Inlet (No Man's Friend and South Jones Creeks), samples were also taken regularly at several stations in Winyah Bay to provide background information for subsequent, more intensive studies of the Bay. The six permanent stations in Winyah Bay are described in Chapter 1, and sampling methods for physical and chemical parameters, zooplankton, and epibenthos are described in Chapter 2. These stations were not sampled as extensively as the NMF and SJ sites, and the data provide only a general description of the characteristics of the bay.

A. CHEMICAL AND PHYSICAL MEASUREMENTS

Due to the nature of the sampling schedule in Winyah Bay, intensive analysis of chemical nutrient availability was not performed. Basic physical parameters were recorded at each station to provide a general understanding of observed differences in densities of zooplankton and epibenthos between the six stations.

Surface water temperatures (Table 9-1) for the Winyah Bay sampling sites ranged from 6.0 to 31.3°C. Bottom water temperatures ranged from 6.3 to 32.8°C. Lowest temperatures were recorded in February and highest temperatures were observed during July and August. Only minor differences in surface and bottom water temperatures were noted between stations. Water temperatures generally increased from February minima to July and August maxima and steadily declined thereafter.

Surface and bottom salinities (Table 9-1) showed wide fluctuations between stations and sampling dates, but no seasonal trends were discernable. Salinities ranged from 0.0 to 34.2 o/oo in surface samples and from 0.9 to 35.2 o/oo in bottom samples. Surface and bottom salinity values were most similar in the three lower Winyah Bay stations (Mother Norton, Mud Bay and Esterville Plantation). Surface salinities for the lower stations ranged from 10.3 to 34.2 o/oo and bottom salinities ranged from 11.1 to 35.2 o/oo. Surface and bottom salinities were also similar for the three upper bay or river stations (Sampit River, Pee Dee River, and Waccamaw River). Surface salinities for these stations ranged from 0.0 to 12.1 o/oo, and bottom salinities ranged from 0.9 to 17.3 o/oo. Surface and bottom salinities in the Sampit River were generally higher than salinities recorded in the Pee Dee and Waccamaw Rivers. Higher salinities in Sampit River water samples reflected the negligible freshwater inflow to Winyah Bay from this source (Trawle and Boland, 1979). Although surface and bottom salinities at a particular station and sampling date rarely differed by more than 10 o/oo, salinity of bottom water was usually greater than surface salinity at each station during all sampling periods. Surface and bottom salinity differences were expected because of the dominance of the flood flow at the bottom and dominance of the ebb flow at the surface during all flow conditions (Trawle and Boland, 1979).

Secchi disk visibility for the Winyah Bay stations ranged from 0.25m -

Table 9-1 Physical and chemical characteristics of water samples collected in Winyah Bay, South Carolina during August, 1980 through July, 1981.

ESTERVILLE PLANTATION									
Cruise No.	1	3	5	7	9	11	13	15	17
Month	AUG	SEP	NOV	DEC	FEB	MAR	APR	JUN	JUL
Water Temperature(°C)									
Surface	31.0	28.8	16.9	10.6	6.0	14.0	21.4	27.3	28.5
Bottom	29.4	28.8	17.0	10.7	6.3	12.5	21.0	27.0	28.3
Salinity (o/oo)									
Surface	16.9	29.6	23.5	12.4	29.7	20.0	11.6	10.3	15.7
Bottom	23.9	30.2	27.6	12.4	30.1	30.6	16.1	11.1	22.5
Secchi Disk (m)	0.65	0.65	0.65	0.35	0.45	0.45	0.35	0.55	0.75
Air Temperature (°C)	26.0	29.0	19.0	18.0	0.0	12.0	24.0	27.0	27.0
MUD BAY									
Water Temperature(°C)									
Surface	30.9	29.2	17.2	10.6	6.0	13.2	21.3	27.4	28.7
Bottom	30.3	29.2	17.4	10.6	6.7	12.5	22.4	27.3	27.8
Salinity (o/oo)									
Surface	18.4	28.1	20.3	19.6	20.8	29.0	20.7	21.2	20.2
Bottom	18.9	28.8	20.0	20.7	27.6	31.7	17.4	11.9	26.3
Secchi Disk (m)	0.55	0.55	0.45	0.55	0.45	0.55	0.35	0.25	0.65
Air Temperature (°C)	25.5	31.0	21.0	14.0	0.0	13.0	22.0	28.0	29.0
MOTHER NORTON									
Water Temperature(°C)									
Surface	30.7	28.7	17.3	11.6	6.0	12.7	20.3	26.8	27.3
Bottom	30.3	28.6	17.0	11.8	6.6	12.7	19.3	26.6	25.8
Salinity (o/oo)									
Surface	28.9	34.2	32.3	33.3	31.3	32.6	31.5	27.2	33.0
Bottom	29.3	34.3	32.0	33.3	33.4	32.8	32.4	29.3	35.2
Secchi Disk (m)	0.55	0.55	0.85	0.55	0.55	0.25	0.35	0.55	0.65
Air Temperature (°C)	26.0	29.0	19.0	12.0	0.0	11.0	23.0	28.0	25.0

Table 9-1 (cont.)

SAMPIT RIVER

Cruise No.	1	3	5	7	9	11	13	15	17
Month	AUG	SEP	NOV	DEC	FEB	MAR	APR	JUN	JUL
Water Temperature (°C)									
Surface	31.3	28.7	16.8	10.1	7.0	13.7	18.0	27.3	30.3
Bottom	32.8	28.3	17.2	12.4	7.0	13.4	28.3	27.1	29.6
Salinity (o/oo)									
Surface	7.3	12.1	10.8	9.1	7.8	2.2	6.5	4.4	7.5
Bottom	17.3	13.9	11.3	10.9	7.8	9.8	6.5	7.6	7.8
Secchi Disk (m)	0.65	0.55	0.45	0.45	0.35	0.35	0.45	0.35	0.45
Air Temperature (°C)	25.5	28.0	20.0	21.0	0.0	13.0	25.0	28.0	31.0

PEE DEE RIVER

Water Temperature (°C)									
Surface	29.0	28.6	16.7	10.5	7.0	13.7	22.0	27.9	30.1
Bottom	29.7	28.6	16.5	10.5	6.8	13.8	22.3	27.3	29.7
Salinity (o/oo)									
Surface	10.0	10.0	7.9	4.7	5.2	2.9	3.7	3.8	4.8
Bottom	10.5	10.4	7.2	4.7	5.3	3.3	4.8	5.6	5.3
Secchi Disk (m)	0.45	0.45	0.45	0.35	0.35	0.35	0.45	0.45	0.45
Air Temperature (°C)	25.0	28.0	20.0	19.0	2.0	14.0	25.0	28.0	31.0

WACCAMAW RIVER

Water Temperature (°C)									
Surface	30.0	28.4	16.7	10.2	7.0	13.9	25.9	28.1	30.3
Bottom	29.5	28.2	16.8	10.1	6.8	13.7	25.9	27.2	29.4
Salinity (o/oo)									
Surface	5.3	5.0	3.2	0.5	0.4	0.5	3.4	2.5	0.0
Bottom	7.1	6.6	7.8	2.8	0.9	1.0	3.9	5.8	3.4
Secchi Disk (m)	0.45	0.45	0.75	0.35	0.35	0.25	0.35	0.45	0.35
Air Temperature (°C)	24.0	27.0	19.0	16.0	2.0	16.0	25.0	30.0	31.0

0.85 m (Table 9-1). Secchi disk readings were highly variable between stations and no definitive seasonal trends were established. Air temperatures (Table 9-1) reflected water temperature patterns with lowest values recorded in February (0 to 2.0°C) and highest values in July or September (29.0 to 31.0°C).

B. ZOOPLANKTON

As with the physical and chemical data, zooplankton collections from the six Winyah Bay stations can be divided into two groups: the lower bay stations (Mother Norton, Mud Bay and Esterville Plantation), the upper bay stations (Waccamaw River, Pee Dee River, Sampit River). Throughout the year, the lower bay stations were consistently more diverse (8-25 categories, mean $\pm$S.D.:18$\pm$5.9; Table 9-2) than upper bay stations (7-20 categories, mean $\pm$S.D.:10.2$\pm$3.7; Table 9-2). Densities of zooplankton were also consistently greater at the lower bay stations (Table 9-3), although there were occasional exceptions (i.e., Pee Dee, March 1981; Sampit River, July 1981; Table 9-3) due to extreme abundance of a single category. Of all stations, Waccamaw River was usually lowest in abundance and diversity (ranked fifth or sixth of seven of nine times; Table 9-3), followed by Pee Dee and Sampit Rivers. Overall, the lower bay stations (MN, MB and EP) had the greatest densities of zooplankton (12,000-13,000m^3), NMF and SJ Creeks had densities of (8100/m^3) similar to those in North Inlet (9200/m^3; Lonsdale and Coull, 1977) and the upper bay densities were lowest (2000-6000/m^3).

As in other locations on the southeast coast, numbers of zooplankton were greatest in the warm months (April - September) and were reduced by

Table 9-2. Relative abundance of zooplankton on major cruises in Winyah Bay. Blanks indicate no organisms were present. Abbreviations are: R = Rare (1 - 100/m^3), C = Common (101 - 1000/m^3), A = Abundant (> 1000/m^3). PD = Pee Dee, WR = Waccamaw, SR = Sampit, EP = Esterville Plantation, MB = Mud Bay, MN = Mother Norton.

	8-15-80						9-26-80						11-7-80					
	PD	WR	SR	EP	MB	MN	PD	WR	SR	EP	MB	MN	PD	WR	SR	EP	MB	MN
Copepods																		
Acartia tonsa	A	A	C	C	A	A	A	C	A	A	A	A	C	R	C	A	A	A
Acartia copepodids	A	C	C	C	C	C	A	C	A	A	A	A	C	C	C	A	A	A
Centropages hamatus																		
Eurytemora affinis																		
Labidocera aestiva				R		R												
Parvocalanus crassirostris				C	R	A	R	R	R	A	A	A	R			C	A	A
Pseudodiaptomus coronatus				R	C	C	R	R	R	R	C	C	R		R	C	C	R
Tortanus setacaudatus																		
Temora turbinata						R				R		C						C
Corycaeus sp.																		
Oithona colcarva				R	R	C	R	R	R	C	C	A	R			R	C	A
Saphirella sp.										R	C	R					C	R
Oncaea venusta						C						R						
Euterpina acutifrons				R		R				C	C	C				R	C	C
Other harpacticoids	R	R			R	R					R						R	
Copepod nauplii	R	R	R	R	R	C	C	C	C	C	A	A	C	R		C	A	A
Copepodids		R		R						R		C	R					C
Meroplankton																		
Coelenterate larvae			C	R	R	R	R	R	R	R		R						
Pilidium larvae(Nemertea)																		
Cyphonautes larvae(Bryozoans)				R		R				R								
Trochophore larvae				R		R												
Polychaete larvae	R		R		R	C	C	C	C	C	C	C	C	R	R	R	C	C
Gastropod veligers	C			R	R	C	C	R	C	R	C	R			R	R	C	R
Bivalve larvae	R	R		C	R	C	R	R			C	C					C	C
Barnacle nauplii	C		A	C	C	R	A	R	C	A	A	C	C		A	A	A	C
Barnacle cyprids		R	R		R		C		R		R						R	
Crab zoeae (other)	C	R	R	C	C	R				R	R	C					R	C
Crab megalopae					R													
Shrimp larvae (other)																		
Decapod larvae (other)						R				R	R	R					R	
Echinoderm larvae (starfish, sea cucumber)										C		C						R
Fish larvae									R									
Others																		
Hydroid polyps							R				R						R	R
Cladocerans	R	A	R					R										
Ostracods					R													
Mysids						R						R						R
Cumaceans																		
Gammarid amphipods											R						R	
Isopods					R	R				R		R				R		R
Lucifer						R												
Chaetognaths						C				R	R	C					R	C
Appendicularians							R	R		C	C	A				R	C	A
Others		R		R	R	C	R	R	R		R	R					R	R

	12-19-80						2-3-81						3-6-81					
	PD	WR	SR	EP	MB	MN	PD	WR	SR	EP	MB	MN	PD	WR	SR	EP	MB	MN
Copepods																		
Acartia tonsa	R		C	A	C	A			R	C	C	C	R		R	C	R	C
Acartia copepodids			C	A	C	A			R	R	R	R			R	C	R	R
Centropages hamatus						R				R	R	A				A	R	A
Eurytemora affinis	C					R	C	C					A	C	A			
Labidocera aestiva						R												
Parvocalanus crassirostris				C	C	A		R		R	R	C				C	C	C
Pseudodiaptomus coronatus			R	R	R	C			R	R								
Tortanus setacaudatus																		
Temora turbinata																		
Corycaeus sp.						R					R						R	
Oithona colcarva				R	R	C	R	R	R	R	R	C				R	C	C
Saphirella sp.						C						R	R					R
Oncaea venusta												R						R
Euterpina acutifrons				R		R						R				R		R
Other harpacticoids	R	R				R	R	R	C					R	R			
Copepod nauplii	R	R	R	A	C	C	C	C	R	C	C	C	C	C	C	C	C	C
Copepodids	C	R				C		C		C	C	A	A	A	A	A	C	A
Meroplankton																		
Coelenterate larvae						R						R					C	R
Pilidium larvae(Nemertea)											R	R						R
Cyphonautes larvae(Bryozoans)												R					R	R
Trochophore larvae						R				R		C			R	R	C	C
Polychaete larvae			R	C	R	C			R	R	R	C					C	C
Gastropod veligers												R						R
Bivalve larvae				R		C				R	R							
Barnacle nauplii	C	R	A	C	C	C	R		C	C	C	A	R	R	C	A	A	A
Barnacle cyprids	R		R	R		C				R					R		R	R
Crab zoeae (other)																		
Crab megalopae																		
Shrimp larvae (other)																		
Decapod larvae (other)																		
Echinoderm larvae (starfish, sea cucumber)																	R	
Fish larvae																		
Others																		
Hydroid polyps						R												
Cladocerans							R	R					R	R	R			
Ostracods													R					
Mysids						R												
Cumaceans																		
Gammarid amphipods	R																	
Isopods																		
Lucifer																		
Chaetognaths						R						R						R
Appendicularians																		
Others	R	R				R	C	C	R			R	R	C	R			R

	4-24-81						6-5-81						7-15-81					
	PD	WR	SR	EP	MB	MN	PD	WR	SR	EP	MB	MN	PD	WR	SR	EP	MB	MN
Copepods																		
Acartia tonsa	C	R	A	A	A	A	A	A	A	A	A	A	A	C	A	A	C	A
Acartia copepodids	C	R	A	A	A	A	A	A	A	A	A	C	C	C	A	C	C	C
Centropages hamatus					R	A												
Eurytemora affinis	R	A	R					R					C	C	R		R	
Labidocera aestiva											R							
Parvocalanus crassirostris				R	C	A				R	A	C	R		R	R	C	A
Pseudodiaptomus coronatus				R	C	C			R	C	C	A	R		R		R	R
Tortanus setacaudatus																		R
Temora turbinata																	R	R
Corycaeus sp.						R												R
Oithona colcarva				R	R	C					R	R	R		R	R	R	A
Saphirella sp.											R	C					R	R
Oncaea venusta												R						R
Euterpina acutifrons						C						R					R	R
Other harpacticoids	R	R		R	R	R			R		R	R	C	R	R	R	R	
Copepod nauplii	R	C	C	C	C	C		C	R	R	C	R	C	R	R	R	R	C
Copepodids		R	R			C					R	R						R
Meroplankton																		
Coelenterate larvae			R	R			R	R		C	C	R	R		C	C	C	R
Pilidium larvae(Nemertea)																		
Cyphonautes larvae(Bryozoans)						R			R		R	C					R	R
Trochophore larvae																		R
Polychaete larvae	R	R	R	R	R	A	R	R	C		C	R	C	R	R	R	R	C
Gastropod veligers				R	R	R	A	C	C	R	C	R	A	C	A		R	R
Bivalve larvae						R					R	R	R				R	R
Barnacle nauplii	R		A	A	C	C	C	C	A	C	A	C	C	C	A	C	C	C
Barnacle cyprids		R		C	A	R	A	A	A	A	A	C	A	C	C	R	C	R
Crab zoeae (other)							C	C	R	C	C	A	A	C	A	R	C	C
Crab megalopae									R		R	R						R
Shrimp larvae (other)											R	R	R				R	
Decapod larvae (other)																	R	
Echinoderm larvae (starfish, sea cucumber)																		R
Fish larvae					R								R					
Others																		
Hydroid polyps												R						
Cladocerans														R				
Ostracods															R			
Mysids				R	R		R	R				C	R					
Cumaceans											R	R						
Gammarid amphipods						R									R			
Isopods				R		R	R					R	R		R		R	
Lucifer																		
Chaetognaths						R					R	R					R	C
Appendicularians											R	R					R	C
Others		R				R	R	R			R	R	C	C	R		R	

Table 9-3. Abundance of common spp. in Winyah Bay, SC (#/m^3). For station designation, see pages 1-10 and 1-13.

Species	Station	AUG	SEP	NOV	DEC	FEB	MAR	APR	JUN	JUL
Acartia tonsa	PD	3657	5611	945	53	-	10	492	9967	3327
	WR	1622	337	30	-	-	-	97	1958	330
	SR	506	4071	505	174	19	68	1493	4198	3332
	EP	452	4909	3785	6678	289	113	33023	3847	2279
	MB	1646	10087	3998	454	109	56	14189	15399	699
	MN	1037	7574	192	1335	216	128	6282	3816	1066
Acartia copepodids	PD	1341	4497	159	8	-	-	164	1554	646
	WR	403	197	158	-	-	-	48	594	150
	SR	194	2175	341	288	10	46	1050	2591	1563
	EP	537	2108	1071	5427	72	103	5907	2276	351
	MB	722	2934	4146	338	40	22	4300	8178	267
	MN	624	4951	202	390	69	58	1384	778	200
Centropages hamatus	PD	-	-	-	-	-	-	-	-	-
	WR	-	-	-	-	-	-	-	-	-
	SR	-	-	-	-	-	-	-	-	-
	EP	-	-	-	-	24	1889	-	-	-
	MB	-	-	-	-	10	56	33	-	-
	MN	-	-	-	41	364	1649	2070	-	-

Table 9-3. Cont.

Species	Station	AUG	SEP	NOV	DEC	FEB	MAR	APR	JUN	JUL
Labidocera aestiva	PD	-	-	-	-	-	-	-	-	-
	WR	-	-	-	-	-	-	-	-	-
	SR	-	-	-	-	-	-	-	-	-
	EP	-	-	-	-	-	-	-	-	-
	MB	9	-	-	-	-	-	-	12	-
	MN	20	-	-	30	-	-	-	-	-
Parvocalanus crassirostris	PD	-	39	46	-	-	-	-	-	9
	WR	-	-	-	-	10	-	-	-	-
	SR	-	22	-	-	-	-	-	-	16
	EP	350	4266	322	326	96	123	100	49	26
	MB	97	1551	139	239	99	201	342	1062	148
	MN	6373	8665	1689	1170	303	790	4413	902	3475
Pseudodiaptomus coronatus	PD	-	49	34	-	-	-	-	-	4
	WR	-	-	-	-	-	-	-	-	-
	SR	-	33	35	7	10	-	-	11	114
	EP	85	404	125	49	24	-	25	173	-
	MB	167	542	231	8	-	-	265	861	28
	MN	544	575	20	124	-	-	237	1284	48

Table 9-3. Cont.

Species	Station	AUG	SEP	NOV	DEC	FEB	MAR	APR	JUN	JUL
Oithona colcarva	PD	-	10	11	-	19	-	-	-	14
	WR	-	-	-	-	10	-	-	-	-
	SR	-	22	-	-	19	-	-	-	18
	EP	60	644	62	16	40	41	13	-	11
	MB	18	333	28	41	40	123	55	12	68
	MN	725	2520	384	118	52	116	213	12	908
Euterpina acutifrons	PD	-	-	-	-	-	-	-	-	-
	WR	-	-	-	-	-	-	-	-	-
	SR	-	-	-	-	-	-	-	-	-
	EP	17	379	10	16	-	10	-	-	-
	MB	-	283	120	-	-	-	22	-	8
	MN	50	575	233	47	26	23	166	25	56
Gastropod veligers	PD	106	733	-	-	-	-	-	3450	2069
	WR	-	9	-	-	-	-	-	165	124
	SR	-	156	47	-	-	-	-	412	2714
	EP	43	13	21	-	-	-	13	12	-
	MB	62	158	37	-	-	22	33	1015	22
	MN	131	59	30	-	9	12	95	99	45

Table 9-3. Cont.

Species	Station	AUG	SEP	NOV	DEC	FEB	MAR	APR	JUN	JUL
Bivalve larvae	PD	10	68	-	-	-	-	-	10	4
	WR	60	28	-	-	-	-	-	-	-
	SR	-	-	-	-	-	-	-	-	-
	EP	-	-	-	16	8	-	-	-	-
	MB	35	100	9	-	20	-	-	35	33
	MN	211	162	121	113	17	-	71	99	43
Barnacle nauplii	PD	347	3226	307	107	37	39	29	182	816
	WR	-	47	-	8	-	10	-	99	90
	SR	1984	2275	1810	1063	400	251	3366	1766	2996
	EP	537	1300	3306	619	625	1673	1066	816	164
	MB	651	1285	2971	239	725	2022	948	2466	482
	MN	30	368	1143	177	441	1208	461	161	179
Barnacle cyprids	PD	68	166	-	15	-	-	10	3440	1147
	WR	10	-	-	-	-	-	12	1089	341
	SR	49	56	-	13	-	23	-	2707	923
	EP	-	-	-	49	8	-	288	1237	11
	MB	18	33	74	-	-	11	1069	1711	122
	MN	-	-	30	130	26	-	59	148	15

Table 9-3. Cont.

Species	Station	AUG	SEP	NOV	DEC	FEB	MAR	APR	JUN	JUL
Crab zoea	PD	289	-	-	8	-	-	-	857	2111
	WR	20	20	-	-	-	-	-	495	557
	SR	88	-	-	-	-	-	-	63	2992
	EP	665	50	-	-	-	-	-	235	45
	MB	229	25	-	-	-	-	-	366	521
	MN	81	118	-	-	-	-	-	1087	356
Crab megalopae	PD	-	-	-	-	-	-	-	-	-
	WR	-	-	-	-	-	-	-	-	-
	SR	-	-	-	-	-	-	-	11	-
	EP	-	-	-	-	-	-	-	-	-
	MB	9	-	-	-	-	-	-	35	-
	MN	-	-	-	-	-	-	-	49	10
Chaetognaths	PD	-	-	-	-	-	-	-	-	-
	WR	-	-	-	-	-	-	-	-	-
	SR	-	-	-	-	-	-	-	-	-
	EP	-	63	-	-	-	-	-	-	-
	MB	-	17	-	-	-	-	-	24	14
	MN	242	103	20	6	-	12	12	99	151

Table 9-3. Cont.

Species	Station	AUG	SEP	NOV	DEC	FEB	MAR	APR	JUN	JUL
Appendicularians	PD	-	29	-	-	-	-	-	-	-
	WR	-	9	-	-	-	-	-	-	-
	SR	-	-	-	-	-	-	-	-	-
	EP	-	316	10	-	-	-	-	-	-
	MB	-	158	-	-	-	-	-	47	2
	MN	-	1002	152	35	-	-	-	12	166
Total Zooplankton	PD	5982	15386	1934	703	1073	12092	882	19722	9726
	WR	5318	1038	248	828	1980	2238	1894	4730	2792
	SR	3054	9078	2891	1712	792	4991	6187	12236	14317
	EP	2858	15450	8836	17182	2108	7103	41050	9065	3291
	MB	3883	19081	13511	1492	2306	4010	21675	32334	3676
	MN	11094	29842	4862	5118	6873	7482	21528	9509	9233

as much as an order of magnitude in the winter (November - March). Densities of meroplankton in particular decreased in the winter months, except for barnacle nauplii and polychaete larvae (Table 9-2). The exceptionally high density in the Pee Dee in March (Table 9-3) was due to one species, *Eurytemora affinis* (Table 9-2), which is characteristic of fresher or less brackish waters. *Eurytemora* peaked in the upper bay between March and July 1981, but was not found there, or was infrequent, between August and December 1980. Species which appeared in the winter in North Inlet and NMF or SJ Creeks, such as *Centropages hamatus*, never occurred in the upper bay stations, so winter diversities were especially low there (Table 9-2). In fact, *C. hamatus* was only abundant at Mother Norton (Table 9-3), although it is a distinct and important winter component of North Inlet (Lonsdale and Coull, 1977).

Lower and upper bay stations differ in the number of dominant species as well as in diversity and abundance. In the lower bay, there are usually more abundant species (Table 9-2), and several are copepods. In the upper bay, rarely more than four species are ever abundant, and only 1-2 of these are copepods. Dominant species in the lower bay are usually similar to dominants in NMF and SJ, including forms such as *Acartia tonsa*, *Parvocalanus crassirostris*, *Pseudocalanus coronatus*, *Oithona colcarva*, and *Euterpina acutifrons*. In the upper bay, however, there are some forms (particularly *Eurytemora affinis* and several cladocerans) which do not occur, or are rare in the lower bay.

Clearly, different species have very different distributions and are abundant at different times. Only *Acartia tonsa* and barnacle nauplii are relatively common at all stations during most times of the year. Many forms, especially meroplankton, are more or less restricted to the lower bay stations, and these are usually most abundant at Mother Norton (i.e., chaetognaths, *Euterpina acutifrons*, crab megalopae, bivalve larvae, appendicularians; Tables 9-2, 9-3). Most of these species also occur only in the warmer months of the year. Categories of larvae which occur year-round (e.g. barnacle nauplii, Table 9-3; polychaete larvae, Table 9-2) probably consist of several species with different spawning periods, but no attempt was made to differentiate between species. At times, one category will suddenly become dominant at a single station (e.g. crab zoeae, Pee Dee and Sampit Rivers, July 1981; gastropod veligers, Pee Dee River June-July, 1981; Table 9-3). Such occurrences represent samples which, were taken at or near the time of peak spawning of one species. In the case of the crab zoeae, the species was the brackish-water xanthid crab, *Rithropanopeus harrisi*, which is not common in North Inlet, NMF or SJ Creeks, or the lower bay.

In summary, zooplankton concentrations and constituents vary considerably throughout the bay, both temporally and spatially. Winyah Bay is an extremely complex system, and considerably more sampling must be performed to elucidate the patterns of abundance and distribution of zooplankton. Winyah Bay sampling has been expanded in the second year of this study, and a more complete description of zooplankton in Winyah Bay will be forthcoming. For the present, the upper bay is obviously different, with fewer and different species present in generally lower numbers. Relatively few species occur in both upper and lower bay stations, and the lower bay closely resembles nearshore coastal and North Inlet environments. Seasonal changes occur throughout the bay, but patterns are not always the same at all locations. The implication of this temporal and spatial variability relative to human activities is that single perturbations which spread throughout the bay may have very different effects on different portions of the waterbody. This makes prediction of potential impacts of human activities particularly difficult unless a considerable body of knowledge exists about the environment.

C. EPIBENTHOS

Mysids or opossum shrimps, were the dominant organisms in sled collections on most cruises at most stations (Table 9-4). *Neomysis americana* was by far the most common mysid in all collections, but low numbers of at least five other species occurred at Mother Norton in August and September. In August, mysid densities were high (40/m^3) at Mother Norton, but low (2/m^3) at all other stations; in September, however, densities in the lower bay decreased, and increased at all other stations, reaching over 60/m^3 in the Waccamaw River.

Mysids were generally more abundant in November (Table 9-5) when they ranged from 79/m^3 (Mud Bay) to 4/m^3 (Sampit River). In December, mysid densities decreased to the annual low (Table 9-5). Densities remained below 15/m^3 at all stations in February and March. The mean density for all stations on the April cruise was the highest since November (Table 9-5). June densities were the highest of the year at most stations. At this time, mysids were most abundant at the Pee Dee and Waccamaw River sites. July densities were significantly lower (Table 9-5).

In summary, mysids were most abundant in fall and early summer, and least abundant in winter and late summer. This pattern differs from that observed in No Man's Friend and South Jones Creeks, where maximum abundance

TABLE 9-4. Dominant organism at each station on each cruise. Station abbreviations are: MN = Mother Norton, MB = Mud Bay, EP = Esterville Plantation, PD = Pee Dee, SR = Sampit River, WR = Waccamaw River, ALL indicates the dominant for the cruise based on mean density for all stations. Organism abbreviations are CH = Chaetognath, MY = Mysid, FL = fish larvae, SL = shrimp larvae, CM = crab megalopae.

MONTH	MN	MB	EP	PD	SR	WR	ALL
AUG	CH	MY	MY	FL	MY	CH	CH
SEP	CH	CH	CH	MY	MY	MY	MY
NOV	CH	MY	MY	MY	MY	MY	MY
DEC	CH	MY	MY	MY	MY	FL	MY
FEB	MY	MY	MY	MY	MY	FL	MY
MAR	CH	CH	MY	MY	MY	FL	MY
APR	CH	MY	MY	MY	MY	MY	MY
JUN	MY	CM	MY	MY	MY	MY	MY
JUL	CH	CH	MY	SL	MY	SL	MY

Table 9-5. Mean number of mysids, amphipods, shrimp larvae, chaetognaths, fish larvae and total organisms per cubic meter for the Winyah Bay cruises from August 1980 through July 1981. Each entry constitutes a mean for 12 sled collections at 6 stations.

MONTH	MYSIDS	AMPHIPODS	SHR. LARV.	CHAET.	FISH LARV.	TOTAL
AUG	7.3	0.2	1.4	13.4	1.2	34.7
SEP	16.1	1.0	0.8	6.8	0.2	29.7
NOV	21.1	1.1	0.1	3.8	0.1	28.2
DEC	2.9	1.2	0	1.1	0.2	5.5
FEB	5.1	1.8	0	0.3	0.5	7.9
MAR	4.6	4.4	0.1	0.3	0.7	10.3
APR	18.4	1.4	0.1	1.0	0.1	22.0
JUN	38.9	1.0	0.9	3.9	0.8	59.2
JUL	4.4	0.7	0.9	3.8	0.1	10.4

occurred in winter at both creeks. However, the Winyah Bay February and March densities were equal to those at NMF (Table 9-5 and Fig. 6-2). Although the data clearly indicate that mysids were the dominant motile epibenthic organisms in Winyah Bay, further analysis of the relationships between physical characteristics of the water column and the abundance and population structure of *Neomysis americana* are necessary before the spatial and temporal distributions of mysids can be discussed in more detail. The sampling program for the second year of this study is designed to provide more specific information on mysid distribution.

Gammarid amphipods were somewhat more abundant at all Winyah Bay stations than at either NMF or SJ Creeks (Tables 9-5 and 6-2), and were collected in almost every sled tow on all cruises. Mean densities for all stations were less than $2/m^3$ from August through February, (Table 9-5). River station densities (WR,PD, and SR) were higher than lower bay stations (EP, MB, and MN) on most cruises. With the exception of the Waccamaw River collections, which yielded the largest catches of amphipods in the study ($20/m^3$), March densities were similar to previous months. Gammarid densities from April through July were less than $4/m^3$, and the means for all stations were comparable to those on the other cruises.

Caprellid amphipods occurred in very low numbers on all cruises. They were most common at stations closest to the ocean. No caprellids were collected in the majority of the sled tows.

Since it was not possible to identify all amphipods collected to species, and since the sled is not a very effective device for collecting organisms which are so strongly associated with the bottom, these results should be regarded only as preliminary assessments of the distribution of these important organisms. High densities of gammarids probably occur in shallow habitats throughout Winyah Bay where they constitute major sources of food for juvenile fishes.

Cumaceans were collected in low numbers on all cruises and were most commonly taken near the ocean. Densities were lower than those of NMF and SJ Creeks during most of the year. Highest densities of the year were observed in November at most stations. On this cruise, the Mud Bay collections yielded over $4/m^3$. Sled catches probably underestimate the actual abundance of these common benthic crustaceans.

Isopods, especially *Aegathoa oculata*, were more common in Winyah Bay than in NMF and SJ Creeks. Highest densities consistently occurred at the high salinity end of the estuary. Mother Norton tows yielded $10/m^3$ in September and $2/m^3$ in November. Otherwise, densities at all stations were less than $2/m^3$. A few isopods were collected at Mother Norton in December, but none occurred at the other stations on this cruise.

Decapod shrimp larvae and juveniles were collected from March through November, but the densities for all stations were highest from June through September (Table 9-5). Mother Norton catches were the largest on all cruises except July. Densities were generally less than $1/m^3$, but annual maxima of more than $3/m^3$ were recorded at Mother Norton and Waccamaw River in August. On this cruise, penaeid shrimp larvae dominated the river collections. Mean densities for all stations were somewhat less than those for NMF and SJ Creeks (Fig. 6-4). Palaemonid shrimp larvae dominated the collection at the Pee Dee and Waccamaw River sites in July (Table 9-4).

The seasonal pattern of abundance of the two sergestid shrimps, *Acetes americanus* and *Lucifer faxoni*, was similar to that observed at NMF and SJ. Both species were most abundant at the lower bay stations. The density of *Acetes* and *Lucifer* at Mother Norton in August was 31/m^3 and 24/m^3, respectively. Densities were less than 4/m^3 for all stations on the other cruises. Only a few of each species were taken in December and none were collected in February and March.

Crab megalopae were most abundant from June through September. Maximum densities were recorded in June at Mud Bay (51/m^3) and Mother Norton (14/m^3). During July, densities were less than 2/m^3 at all stations, but crab megalopae were the dominant organisms in the sled collections at Mud Bay in June and July (Table 9-4). In August and September, Mother Norton densities were higher than all other stations. Lower bay collections contained a variety of species of megalopae, while the river collections were comprised chiefly of fiddler crab (*Uca spp.*) megalopae. Generally, the seasonal pattern of abundance for all megalopae at the Winyah Bay stations was similar to that at NMF and SJ Creeks, where June peaks were also recorded.

Chaetognaths or arrow worms often dominated the sled catches at the lower bay stations (Table 9-4). Maximum densities usually occurred near the ocean, especially at Mother Norton. The mean for all stations decreased from an annual high in August to the annual low in February and March, then increased in June and July (Table 9-5). Few chaetognaths were collected in the upper bay from December through March.

Fish larval densities were generally lower at the Winyah Bay stations than at NMF and SJ Creeks (Table 9-5 and Fig. 6-9). Some larvae were taken every month, but densities were highest in August, March and June. In August, Mother Norton catches (6/m^3) included sciaenids, anchovies, and gobies. September collections in the lower bay were smaller, but the same families were represented. In November and December, croaker larvae were collected at most stations. Young-of-the-year spot, summer and southern flounder, speckled worm and American eel, and pinfish larvae occurred at most stations. In addition to these species, March samples contained pipefish and clupeid (herring) larvae. Clupeids were more common in the river collections. April collections were characterized by lower numbers of large croaker, spot and pinfish larvae. In June, fish larval diversity increased considerably. Whiting, silver perch, star drum, hogchoker, goby, blenny and anchovy larvae were collected throughout the estuary. No major changes in composition were recorded in July, although densities were much lower than in June (Table 9-5).

Several factors are probably responsible for the relatively low densities of fish larvae collected at the Winyah Bay stations. One factor is related to the duration or longevity of early life stages. The developmental time from egg to postlarva is on the order of weeks for most estuarine fishes, and even though larvae representing most of species were collected with the sled, species with short spawning and developmental times were probably missed during the six week interval between cruises. Another factor is station location. Fish larvae are more common in shallow water than in the relatively deep channels and open waterways where the first year stations were located. Also, avoidance of the collection apparatus by fish larvae most likely contributed to the low numbers in the collections. In summary, low densities of larvae determined in this study are probably the result of under-sampling, rather than to low numbers of larval fishes in the estuary.

A more detailed analysis of the spatial and temporal distribution of major fish species will be conducted after the second year sled study in Winyah Bay is complete. Preliminary analyses indicate that certain stages (sizes) of many species occur in different sections of the estuary (ocean to river) as they develop. For instance, spot larvae appeared to be much more abundant in the creeks than in the Winyah Bay channel stations, while croaker seemed to be more common at the bay and river stations than either NMF or SJ Creeks.

In summary, organisms were most abundant in the lower bay during the warmest months. The diversity of organisms was also greater nearest the ocean. Fifteen of the seventeen categories of animals identified in sled samples at NMF and SJ Creeks were collected at Mother Norton Shoal in the lower bay, but only eight of these categories were represented at the Waccamaw and Pee Dee River sites. Mysid shrimps were the most abundant motile epibenthic organisms at all stations (Table 9-4).

The diversity of organisms at all stations was greater between April and November than during the winter. The seasonal patterns of abundance for all species in Winyah Bay, with the notable exception of mysids, were consistent with trends at NMF and SJ. Densities of total organisms in sled collections at NMF, SJ and Winyah Bay were greatest in June (Fig. 6-10 and Table 9-5).

A great deal of variability in the spatial and temporal distribution of motile epibenthic organisms was apparent from the analysis of the first year's collections. Much more study of the ecology of early life stages of shrimps, crabs, and fishes in Winyah Bay are necessary before the impacts of petroleum and other pollutants can be predicted accurately, but these data indicate that such impacts could have immediate and long-term effects on estuarine populations.

CHAPTER 10. IMPACTS OF PETROLEUM ON ESTUARINE ECOSYSTEMS; PROJECTIONS FOR WINYAH BAY

Estuarine and coastal areas receive petroleum hydrocarbon inputs from many sources, including natural seeps, offshore production (blowouts, ruptured lines, accidents, normal operational discharges), transportation losses (tanker accidents, dry docking, normal terminal operations, bilge cleaning, nontanker accidents), coastal refineries (normal and accidental discharges), the atmosphere, coastal municipal wastes and industrial wastes, urban and river runoff. Discharges into the marine environment have been summarized in the National Academy of Sciences report on petroleum in the marine environment (NAS, 1975).

Crude oil contains many different components which vary according to molecular size and type. Degradation processes for crude oil and various chemically dispersed oils have been described in NAS (1975) and the Proceedings of the 1981 Oil Spill Conference (American Petroleum Inst., 1981). Oil released to the aquatic environment immediately undergoes many alterations. Initially spilled oils spread rapidly into thin layers, forming an oil slick. Hydrocarbons less than 15 Carbon molecules long evaporate and are volatilized from the surface waters within 10 days (Kreider, 1971). Other hydrocarbons are dissolved or form particles, many of which settle into the sediments. Hydrocarbons also form tarballs, and some are removed by photochemical oxidation. Petroleum products are also subject to microbial degradation and uptake by organisms.

Impacts of hydrocarbons on estuarine organisms are influenced by many factors, including amount of oil released, type of oil (crude oils are generally less toxic than the refined fractions), solubility of the oil, and reactions with dispersants. Dispersants used to treat oil spills, or dispersant/oil combinations, may be more biologically damaging than the hydrocarbons which were initially released. Currents, circulation, morphometry of the area, and meteorological conditions can also affect toxicity. Highly turbulent zones such as sandy beaches are usually less sensitive to oil spills than estuaries and salt marshes (Gundlach and Hayes, 1978). High current and wind velocities in the open sea during storm conditions may disperse oils more quickly, thereby reducing their impact. However, in enclosed areas, such conditions may spread the oil over large, more sensitive areas (e.g., salt marsh and estuarine communities). Turbulent factors also increase the suspension of particulate materials to which oil adheres. Greater concentrations of oil are carried to bottom sediments when turbidity is greatest. Timing of the impact is also important because spills during the warmer months of the year are more likely to affect sensitive larval stages and reproductively active adults.

Several mechanisms have been described through which plants and animals are exposed to oil. Direct contact is the most obvious method and is often responsible for decreased growth, fouling of feeding and swimming structures, or death. Hydrocarbons can be absorbed through the body walls of many organisms. Other mechanisms include ingestion of oiled particles and food chain transfer through ingestion of contaminated prey items. Impacts vary depending on mode of contact, duration, exposure, and type of oil or oil fraction. Effects may be categorized as being acute or chronic. Acute effects are generally immediate and severe, and may include death or debilitation. Acute exposure to aromatics during the first few days after an oil spill may be responsible for many of the reported fish and bird kills, and population declines of plankton and larvae. Chronic effects generally result from continued exposure to refinery effluents, repeated small spills, or resuspension of contaminated benthic sediments, and may be lethal or sublethal.

A complete review of all pertinent literature was not feasible in this study, but we have cited many excellent articles and reviews which describe case histories of actual oil spills (e.g., American Petroleum Institute, 1981; NAS, 1975). We wish to summarize the abundant literature, particularly emphasizing acute and chronic effects of petroleum upon groups of organisms which are likely to be most severely affected in Winyah Bay. A review of potential effects by group is followed by predictions of potential impacts on Winyah Bay, based on current knowledge and information obtained in this study regarding the bay and important exchange areas.

Phytoplankton and Macrophytes

The effects of petroleum hydrocarbons on phytoplankton have been previously reviewed (Corner, 1978; Johnson, 1977; Snow, undated; Vandermeulen and Ahern, 1976). Effects vary depending on the sensitivity of the species and the concentration of oil to which they are exposed (Dunstan et al., 1975; Mironov, 1968, 1972; Mironov and Lanskaya, 1966; Pulich et al., 1974; Thomas et al., 1980). Species sensitivity is governed by many factors, especially physiological condition (Stoll and

Guillard, 1974). The severity of an oil spill also varies seasonally and is generally greater during spring or summer months (Gordon and Prouse, 1972; Fontaine et al., 1975). Other factors, including water solubility (Currier, 1951; Kauss et al., 1973) and reactions with dispersants affect hydrocarbon toxicity (Batelle, 1973; Scott et al., 1979).

Heavy concentrations of crude oil have long been known to inhibit phytoplankton growth (Galtsoff et al., 1935). More recent laboratory studies have adequately demonstrated the detrimental effects of petroleum hydrocarbons on both marine phytoplankton (Mironov and Lanskaya, 1969; Mommaerts-Billet, 1973; Pulich et al., 1974) and freshwater species (Kauss and Hutchinson, 1975; Soho et al., 1975a,b). Extensive damages following actual oil spills have also been described (Diaz-Piferrer, 1962; Clark et al., 1973).

Specific effects of oil exposure include inhibition of cell division and subsequent reductions in cell number (Mironov and Lanskaya, 1966), inhibition of photosynthesis (Gordon and Prouse, 1972), reduction of CO_2 exchange (Shiels et al., 1973), damage to the plasma membrane (Van Overbeck and Blondeau, 1954), inhibition of oxidative phosphorylation (Vandermeulen and Ahern, 1976), modification of DNA and RNA polymerization (Davavin et al., 1975) and elimination of bicarbonate uptake (Kauss et al., 1973).

Low concentrations of oil stimulate growth and photosynthesis in some species (Snow and Scott, 1975; Shiels et al., 1973). Some hydrocarbon fractions inhibit photosynthesis at all concentrations (Parsons et al., 1976) and phytoplankton populations may never recover after initial exposure to hydrocarbons (Lee et al., 1977). Generally, the lag phase in population growth is lengthened and the exponential phase is depressed. Recovery of phytoplankton populations after initial inhibition has been related to large evaporative losses of hydrocarbons (Vandermeulen and Ahern, 1976; Lacaze, 1974; Mahoney and Haskin, 1980).

The effects of oil on macrophytes has been reviewed by Johnson (1977) and Snow (Undated). Several studies have examined the impacts of acute oil spills on marshes (Stebbings, 1968; Burns and Teal, 1971; Lytle, 1975; Macko et al., 1981; Bender et al., 1977; Hershner and Moore, 1977) and prolonged exposure to refinery effluents (Baker, 1976a,b; Dicks, 1976). Results generally indicate that marsh grasses can survive a single mild exposure to oil, but multiple doses may be fatal.

Responses of macrophytes to hydrocarbon exposure are varied. Effects may be severe, and large macrophyte communities may virtually disappear (Ranwell, 1968; Anonymous, 1953). Reported increases in phytoplankton and macrophyte populations after exposure may be due largely to the decimation of herbivore populations (North et al., 1965; Miller et al., 1978; Johansson et al., 1980). Seed germination may be almost completely inhibited after exposure to crude oil (Baker, 1971). Stands of *Spartina alterniflora* exposed to multiple doses of oil experience serious lethal effects and many sublethal effects, including delayed development, increased density, reduced mean weight per stem, and suppression of cohort production (Hershner and Lake, 1980).

Zooplankton

Contact with hydrocarbons can result in a variety of effects in zooplankton which differ from species to species. Some forms may simply rid themselves of the hydrocarbons (depuration) with relatively little negative effect; others may metabolize it to less toxic forms and store it in lipids or other compounds (Sanborn and Malins, 1977), whence it can be passed up the food chain; in other instances sublethal effects such as reduced offspring number or lifespan can be induced; finally, contact with hydrocarbons or dispersants can have direct lethal effects.

Numerous studies (e.g., Wells, undated; NAS, 1975) have documented direct death in zooplankton populations from contact with hydrocarbons, both in the field and in the laboratory. On the other hand, Conover (1971) found relatively little effect of oil on copepods, and showed that ingestion of oil could result in transport of up to 20% of the oil from the surface to the bottom in the form of fecal pellets. Other studies have shown that zooplankton ingest oil in particles of various sizes (Wells, undated), that feeding rates or particle selection can be modified by the presence of various sizes of oil particles (Berman and Heinle, 1980), and that rate of depuration of oil may depend upon whether it was ingested (slower) or taken up through the body wall (faster; Corner et al., 1976). The effect in any given survey or experiment depends on types of oil or oil fraction, concentration, time of exposure, environmental conditions (temperature, salinity, etc.) and species of zooplankton.

Sublethal effects are the most difficult to document, and are often hard to recognize. In addition, the impact of various sublethal effects on zooplankton populations is difficult to predict because of the lack of understanding of zooplankton biology in general. Documented sublethal effects of exposure to oil include changes in rates of feeding, reduction of activity levels (e.g., immobilization or narcotization), behavioral changes (e.g., loss of orientation, loss of ability to select substrates, loss of sensory abilities), physiological effects (e.g., reduced respiration/excretion rates), and life history effects (e.g., reduced clutch size, clutches per lifetime, offspring viability, or adult life span). The variety of sublethal effects on zooplankton are reviewed in Wells (Undated).

Studies performed on zooplankton (usually in boreal or temperate waters) have shown that most zooplankton as individuals are very sensitive to dispersed and dissolved petroleum (NAS, 1975; Wells, undated). This sensitivity must be considered in light of the great diversity of zooplankton and the variety of oil types and fractions they might contact. Considerable work has been performed on some groups, especially protozoans, coelenterates, ctenophores, polychaetes, molluscs, crustaceans (especially barnacles, copepods, amphipods, mysids, shrimps and crabs), echinoderms, and fishes. Other groups largely have been ignored, such as foraminiferans and radiolarians, cladocerans, ostracods, cumaceans, isopods, larvaceans (appendicularians), and chaetognaths. In most cases, the groups mentioned above have not been studied in the southeastern United States, except for the Gulf coast of Louisiana and Texas. Although results vary, some forms (i.e., ctenophores and decapod larvae) appear to be particularly sensitive to hydrocarbons. Decapod larvae are more susceptible during molting, or in the early stages of development. some studies have shown that barnacle larvae are fairly sensitive (Wells, undated), but others (e.g., Lee and Nicol, 1977) have shown that they are more resistant than most copepods. Sensitivity of molluscs and echinoderms varies, but early cleavage stages are usually more sensitive than eggs or adults (Wells, undated).

Few toxicity studies have been performed on species which are found in the study area; in a recent review of the literature on zooplankton from Cape Hatteras to Cape Canaveral, Alden (1977) cited no studies of oil effects on southeastern plankton. Lee and Nicol (1977) studied effects of No. 2 crude oil on coastal/oceanic zooplankton in the Gulf of Mexico, and concluded that although coastal zooplankton were more tolerant of the water-soluble fractions (WSF) than the oceanic forms, they still suffered negative effects ranging from reduced survival to behavioral aberrations. They attributed differences between coastal and oceanic zooplankton to the fact that there were larger numbers of particularly resistant forms (barnacle nauplii, polychaete larvae) in the coastal plankton, and speculated that holoplanktonic forms were more sensitive.

Studies of *Eurytemora affinis* (reviewed by Dawson, 1979), a species which occurs in upper Winyah Bay, showed that ingestion rates were reduced by 38% in concentrations of oil which might be found under a spill (0.52 mg/l). Exposures to more than 1 mg/l resulted in narcotization and death. Numerous life history effects were also recorded, including reduction in adult life span, clutch size, and number of eggs/lifetime when *E. affinis* were exposed to WSF or Naphthalene. Exposure to concentrations of hydrocarbons for less than 4 hours (as under a spill) could have significant negative sublethal effects on *E. affinis* life history parameters.

Numerous studies have been performed on species of *Acartia*, including *A. tonsa*. Berman and Heinle (1980) found that concentrations of fuel oil of 70 ug/l did not affect feeding, but concentrations of 250 ug/l resulted in several different types of feeding modifications, from reduced feeding rate to changes in the sizes of particles filtered. Hebert and Poulet (1980) reported that exposure to Venezuelan crude oil rapidly and significantly reduced growth and survival of *Acartia hudsonica*, and that feeding behavior and particle size selection were also affected. Ott (1980) found that egg production was significantly depressed by exposure to 50 ug/l napthalene, and that young females were more sensitive than older females. In addition, a higher percentage of infertile eggs were produced during early exposures to naphthalene.

Studies on locally-occurring crabs generally bear out the results of investigations in other areas: early larval stages are more sensitive. Laughlin, Young and Neff (1978), working with *Rhithropanopeus harrisii* (a species which occurs in the fresher waters of Winyah Bay) found that all larval stages were negatively affected by exposure to sublethal concentrations of water-soluble fractions of No. 2 fuel oil. Earlier stages were more sensitive, but later stages, including megalopae and adults, appeared to recover from chronic sublethal exposure. The major effect of chronic exposure on these crabs may be reduction in population size or viability due to reduced recruitment into the adult population. Cucci and Epifanio (1979) found negative effects in larvae of the mud crab *Eurypanopeus depressus* when exposed to various concentrations of

WSF of Kuwait crude oil; as with previous investigators, they found more effects in earlier stages, but also a greater incidence of morphologically abnormal megalopae after exposure.

In summary, effects of exposure to various types and concentrations of hydrocarbons appear to have similar impacts on southeastern zooplankton as on plankton studied in other parts of the world. These may range from immediate mortality to relatively innocuous and temporary behavioral modifications. The degree of impact can vary considerably depending upon exposure, species, life stage of the organism and environmental conditions.

Benthic and Intertidal Organisms

Many studies have shown that petroleum products cause a variety of lethal and sublethal effects in marine and estuarine organisms, including benthic or epibenthic forms (reviewed in NAS, 1975; Percy, undated). One of the important variables governing the impact of oil is habitat type; oil on a high energy coastline may be rapidly removed, whereas if it impinges on low-energy environments, considerable time may be required to disperse it. Gundlach and Hayes (1978) have developed a vulnerability index which indicates that inter- and subtidal habitats in estuaries like Winyah Bay/North Inlet are among the most difficult to clean, and once inundated with oil, take the longest time to return to normal conditions (Sanders et al., 1980). This is largely because estuarine inter- and subtidal habitats contain fine, porous mud-sand substrates which readily incorporate and retain oils under the low-energy hydrographic regime in which they occur.

Intertidal organisms are especially susceptible to physical damage (coating, smothering, fouling) by oil because of their exposed position (Straughan, 1972). Fine particulate material is coated with oil and incorporated into inter- and subtidal sediments, from which toxic hydrocarbon fractions can leach for long periods of time. Many authors believe that intertidal organisms are actually less susceptible to oil inundation than subtidal animals because of their inherent resistance to physical stresses (Newell, 1970), but direct negative effects (e.g., reduced growth or metabilism, behavioral aberrations, mortality) from spills have been demonstrated for most benthic taxa (George, 1970; Rossi and Anderson, 1978; Thomas, 1978) both inter- and subtidally.

Most benthic organisms rapidly take up hydrocarbon fractions, which cause various physiological, behavioral, and metabolic effects; many of these organisms quickly depurate hydrocarbons when put into clean water (Lee, 1977). There is usually rapid uptake and loss to a stable level in which some hydrocarbon fraction remains in the organisms in a detoxified or metabolized form (e.g., Anderson, 1975). Such stored hydrocarbons can be passed up the food chain, reaching even humans in the case of commercially important species like oysters, clams, shrimps and crabs.

Sublethal effects on benthic organisms are numerous, and include reduced or increased respiration rates (Gilfillan, 1973; Percy, 1977), formation of neoplastic lesions (Albeau Fernat and Laur, 1970; Yevich and Barszcz, 1976), narcosis or reduced muscular activity (e.g., Corner et al., 1976), and reduction of chemosensory ability (Atema et al., 1973; Pearson and Olla, 1979). Modification of growth rate, molting ability or frequency, and reproductive processes are especially important sublethal effects which have major implications for populations of benthic and intertidal invertebrates. The vast literature on these subjects reports considerable differences in the degree to which exposure to petroleum causes sublethal effects among taxa (Percy,undated), but nearly all species studied to date are affected to some degree.

Larvae and juveniles of benthic organisms are more severely affected by contact with petroleum than adults. Larvae of many commercially important species (e.g., crabs, oysters, clams) as well as non-commercial forms (e.g., polychaetes, barnacles) have been shown to be injured in various ways by petroleum fractions (Caldwell et al., 1977; Byrne and Calder, 1977), and death of larvae or of newly settled or hatched juveniles (e.g. Edwards, 1980; Woodin et al., 1972) has frequently been recorded. Although Tatem, Cox and Anderson (1978) found that young penaeid shrimp were more resistant than older shrimp, the opposite is true for most benthic invertebrates. One of the major effects of oil spills on benthic/ intertidal organisms is the reduction of population size or viability by loss of recruits.

In summary, benthic and intertidal organisms suffer negative impacts from acute exposure to hydrocarbons and from long-term chronic exposure. Although the effects vary between species and habitats, they are generally negative, and may lead to significant changes in the quality of the ecosystem or the value of the resources which may be taken from the system.

Fish

Impacts of oil spills on fish populations are variable, and range from little or no effect to large fish kills (Gooding, 1968; Cerame-Vivas, 1968). In creeks receiving chronic discharges of oil field wastes, 5-16 times fewer gamefish were harvested and yields of blue crabs and forage fish showed similar declines (Spears, 1971). These adverse impacts were thought to extend into the bay which received the creek input. Petroleum-based hydrocarbons are magnified in the food web (Lu and Metcalf, 1975; NAS, 1975; Koons et al., 1976), and therefore may pose a more serious hazard to higher trophic level organisms such as fish. Effects of oil exposure depend upon many environmental conditions, including salinity and temperature (Lindén et al., 1979). Effects of chronic oil exposure may be most severe to fish species which are year-round residents and are frequently in contact with bottom sediments such as flounders and eels (Fletcher et al., 1981), or feed on bottom organisms, such as the endangered short-nosed sturgeon.

Primary stress responses include increases in osmolality, concentrations of plasma glucose (hyperglycemia) and cholesterol (Thomas et al., 1980), and increased respiratory (or opercular) rates (Thomas and Rice, 1975; Brocksen and Bailey, 1973). Other possible effects include decreased growth rates (Hawkes, 1977; McCain et al., 1978), increased liver to body weight ratios (Yarbrough et al., 1976), fin rot (Minchew and Yarbrough, 1977), severe damage to gill epithelial tissue (Nuwayhid and Davies, 1980; Clark, Finley and Gibson, 1974; Blanton and Robinson, 1973), induction of benzo(a)pyrene monooxygenase activity (Kurelec et al., 1977; Payne and Penrose, 1975; Payne, 1976), and histological damage to chemoreceptors (Gardner et al., 1973). Oil exposure also may result in the tainting of fish flesh (Mackie et al., 1972; Blumer, Souza and Sass, 1970; Shipton et al., 1970).

Fish larvae are very susceptible to oil pollution and treatment with dispersants (Wilson, 1977), although species differ as to their sensitivity (Kuhnold, 1970). Larval effects also include disruption of phototactic and feeding behavior (Wilson, 1970). Fry show avoidance reactions to hydrocarbons, which may disrupt migrations (Rice, 1973).

Fish embryos exposed to oil experienced decreased hatching, damage to liver, kidney, lens and epithelial tissues, mitochondrial damage (Ernst and Neff, 1977; Cameron and Smith, 1980), and decreased survival (Linden, 1978). Bouyant fish eggs tend to congregate at the water surface and are especially susceptible to the effects of toxins. Effects of treatment with oil dispersants include abnormalities in cell division and differentiation, reductions in heart rate, eye pigmentation, growth rate, and hatching success (Wilson, 1976).

Birds

Of the groups of vertebrate animals that are exposed to oil pollution, birds are probably the most adversely affected (see reviews by NAS, 1975; Brown, undated). Diving birds in particular are severely affected by oil spills. This group includes the familiar pelicans, coots, cormorants, loons, grebes, mergansers, and the highly gregarious diving ducks. For example, nearly half of the Tay estuary population of diving sea ducks was lost in 1968 as a result of the Tank Duchess oil spill (Greenwood and Keddie, 1968). The size of the oil spill usually gives no indication of the magnitude of the damage. More than 5,500 birds were killed by the leakage of only about 27 tons of oil from the barge Irving Whale along the coast of Newfoundland (Brown et al., 1973).

One of the most serious effects on birds is the breakdown of feather structure, which results in loss of waterproofing and insulation (Hartung, 1967). This condition leads to severe thermal stress and may often result in the death of the afflicted bird.

Oil is ingested by birds through preening activity (Hartung, 1965) and feeding on contaminated prey organisms. Ingested oil has been reported to cause heterotrophy of the nasal gland, liver, adrenals, and changes in the morphology of intestinal tissues in some birds (Miller et al., 1978b). Other possible effects include physiological stress (Butler et al., 1979; Crocker et al., 1974, 1975), inhibition of nutrient transfer (Miller et al, 1978a,b) reduction of growth (Miller et al., 1978a) and narcotization (Southward, 1978). Crude oil ingested by female birds causes reproductive success to decline by decreasing egg production, hatchability, and egg shell thickness (Hartung, 1965; Holmes et al., 1978; Grau et al., 1977), and by reducing survival of offspring produced by these birds (Vangilder and Peterle, 1980).

Oil may easily be transferred to the surface of eggs by oiled parents during incubation. Experimentally applied oil resulted in the death of embryos of mallards, eiders, herons, gulls and terns (Albers, 1977; Coon et al., 1979; Hartung, 1965; Szaro and Albers, 1977; White et al., 1979). When female mallards were smeared with only 5 ml of mineral oil, the eggs didn't hatch.

In summary, bird populations may be severely affected by oil spills. Adverse impacts are likely to be most serious in areas where birds are highly concentrated, especially breeding and feeding grounds and in waters adjacent to major migratory flyways.

Mammals

Very little is known about the potential impacts of an oil spill on mammals. Although the effect of oil on muskrats has been documented (McEwan et al., 1974), most of the existing information regarding effects on mammals pertains to groups which occur outside of the study area, such as seals (refer to Geraci and Smith, 1976; Smiley, undated, for lists of pertinent references).

Specific effects may include damage to appendages (Warner, 1969; Davis and Anderson, 1976), eye irritation (Geraci and Smith, 1977), reduction of insulating properties of fur (Kooyman et al., 1977) and the formation of mild kidney lesions (Smith and Geraci, 1975).

Summary and Predictions for Winyah Bay

Potential acute and long-term effects of a large oil spill in salt marsh and estuarine environments have been considered in this chapter, as well as effects of low-level chronic hydrocarbon inputs. Marine organisms are exposed to hydrocarbons through four basic mechanisms: direct contact,uptake of dissolved fractions through the body wall, ingestion of contaminated prey organisms, and direct ingestion of oil or oil-laden particles. Hydrocarbons can cause acute (direct) or sublethal effects in organisms, which range from immediate death to reduced growth and reproduction.

Toxicity of hydrocarbons may vary for a number of reasons. Direct contact produces the most immediate and damaging effects, but ingestion or uptake also cause lethal and sublethal damage. Impacts vary according to the amount and types of oils involved, and highly refined fractions are frequently most toxic. Dispersants and dispersant/oil combinations sometimes result in more significant adverse impacts than the oil itself. Populations of highly sensitive species may be totally destroyed, whereas other species may suffer less dramatic sublethal effects, and species of low sensitivity may actually experience sudden dramatic population increases (Sanders et al.,1980).

Susceptibility of organisms varies with habit and stage of life cycle. Heavily oiled marsh grasses, such as *Spartina alterniflora,* will die, and less-heavily contaminated grasses will experience sublethal effects, including decreased growth and inhibition of seed germination. Buoyant eggs and surface-dwelling organisms will be affected by direct contact, while animals and plants in the middle part of the water column will be most severely affected by the water-soluble fractions and by contact with or ingestion of oiled particles. Benthic and intertidal organisms will be affected by smothering, direct contact with or ingestion of oiled sediments. Larger, more motile animals (fishes, shrimps, and crabs) may or may not be able to avoid direct contact, but will still be affected by ingestion of hydrocarbon-containing organisms lower on the food chain or absorption of water-soluble fractions through their body walls.

Effects of oil on aquatic organisms often vary seasonally, and are generally more severe during the warmer months when larval and planktonic forms are abundant and when reproductive activity is high. Many commercially important species may be affected, particularly in the larval (decapods, shrimps, fish) or the newly-settled juvenile (clams, oysters) stages. Soft-bodied forms (e.g., ctenophores, jellyfish, and appendicularians) are poorly studied, but appear to be especially sensitive to hydrocarbon pollution.

Birds are abundant in highly productive estuarine systems and are probably the most severely affected vertebrate group; oil spills may result in almost total destruction of local populations. Spills adjacent to breeding, feeding and rafting areas result in an unusually high number of casualties and may severely affect population levels for many years. Temporary visitors may also experience adverse effects, especially when oil spills occur in areas adjacent to major flyways of birds or migration routes of aquatic organisms (e.g., marine turtles, anadromous and catadromous fishes).

The most extensive long-term study of the effects of an oil spill in an estuarine habitat (Sanders et al., 1980) showed that negative impacts, such as instability in density, diversity and species richness; and physiological and behavioral disorders, persisted as long as seven years after the initial spill. There is no reason to believe that similar habitats along the east coast of the United States would behave differently, or would be less affected by an oil spill.

Estuarine areas subject to chronic low-level hydrocarbon inputs, such as those receiving refinery effluents, experience high mortalities of marsh grasses near the area and changes of species composition and abundance of both flora and fauna. Areas near the effluent source suffer the most severe impacts, and pollutants accumulate over time, particularly in systems with low circulation properties. Effects are less likely to be acute, but sublethal effects may be widespread. Reduced catches of commercially important species (fishes, and crabs) and forage species are likely to occur in adjacent bays receiving the effluent.

In a broad, relatively shallow estuary like Winyah Bay, one would expect an oil spill to spread rapidly throughout a large portion of the bay, coming in direct contact with intertidal marshes, oyster bars and mudflats, all designated as highly sensitive areas (Gundlach and Hayes, 1978). Because of the high amount of suspended particulates in the bay, there would be rapid incorporation of oiled particles into the sediments, particularly in areas with high sedimentation rates such as Mud Bay. Over several tidal cycles, oil would be carried into the nearshore environment, impinging upon sandy beaches on North, South, Sand and possibly even Cape Islands. Removal from these beaches would occur relatively rapidly (Gundlach and Hayes, 1978). However, severe impacts on the nests of loggerhead turtles on these beaches would be expected if the spill occurred during the nesting season. Nests which occur inside the bay on beaches (i.e., Cat Island) would also be affected. Oil would probably be transported to adjacent aquatic systems including the Santee River and North Inlet via the intracoastal waterway and NMF and SJ Creeks. All protected and natural habitats presently bordering the bay would receive at least some direct oiling. These effects would be exacerbated during times of high water movement, such as spring tides, storms, or periods of high winds. Wind direction would play a major role in determining which shores of the bay would be most heavily oiled.

An oil spill would probably have severe negative impacts on most of the flora and fauna which occur within the bay. The vast borders of *Spartina alterniflora* would be killed by direct contact, and plants which survived would probably suffer long-term sublethal effects. Phytoplankton in the area of the spill would be killed, but subsequent phytoplankton blooms would occur after most of the oil was incorporated into the sediments or shoreline. Many of the native intertidal invertebrates, particularly fiddler crabs, oysters, mussels, snails and barnacles would suffer direct mortality by contact with oil. Survivors would be expected to experience sublethal effects, including behavioral and physiological disorders, reduced growth and reduced or aberrant reproduction for many years.Populations of intertidal invertebrates would drop, and recover slowly, due to reduced recruitment by larvae and juveniles, and subsequent death of recruits exposed to hydrocarbons leaching from oiled sediments. Subtidal benthic and epibenthic organisms, including polychaetes, clams, numerous small shrimps, mysids, amphipods and fish larvae would be killed or damaged by direct contact with oil or oiled sediments, or by ingestion of oiled organisms or particles. Recruitment into muddy or muddy-sandy sediments would be greatly reduced, and benthic communities might take years to recover due to fundamental changes in sediment characteristics brought about by the deaths of the structuring organisms living within the sediments. Bottom-feeding organisms, including threatened or endangered species like the shortnose sturgeon and loggerhead turtle, would suffer by loss of their food sources and by ingestion of oiled organisms. So little is known about these organisms that prediction of sublethal effects is impossible.

In the water column, zooplankton near the spill would probably be killed by direct contact or uptake of hydrocarbons. Recovery of common species such as *Eurytemora affinis* and *Acartia tonsa* would probably be rapid due to recruitment from adjacent systems, but subsequent zooplankton populations may be reduced from normal levels and continue to experience sublethal effects. Populations of motile organisms which depend upon the plankton and other food resources within the bay would decline. Catches of commercially important fishes, forage fishes, crabs and shrimps would also drop. Recruitment would be slow due to deaths of larvae (particularly of decapods and fish). Adults of the motile forms like the blue crab and numerous fishes might leave the bay and avoid it as long as hydrocarbons remained. Organisms with sensory apparati affected by the hydrocarbons might continue to enter the bay, only to suffer sublethal effects caused by hydrocarbon uptake and ingestion.

Bird populations in the area would be severely damaged even by a small spill, with dramatic mortalities of white ibis, pelicans, cormorants, gulls and terns, waders and divers. Those which survived or avoided direct oiling would suffer sublethal effects such as nervous disorders or reduced reproduction due to ingested oil. Predatory birds, including the bald eagle, peregrine falcon and osprey, would suffer sublethal effects from ingestion and concentration of hydrocarbon fractions.

In short, even a brief review of the oil spill literature indicates that an estuary like Winyah Bay would suffer severe negative impacts if an oil spill occurred. Data from the one long-term study of such a spill in a marsh area (Sanders et al., 1980) indicate that recovery would take many years, and complete recovery may never occur.

Whereas acute poisoning of organisms from oil or chemical spills is relatively simple to detect, sublethal effects of chronic or low-level inputs of hydrocarbons may not become apparent for years or decades. The chronic pollution of upper Winyah Bay, especially the Sampit River, by local industry has already caused extensive damage to benthic communities in this area. Oil droplets discharged into silt-laden, slow-flowing waters would accumulate on the bottom in the form of an oily sludge. The rate at which oiled sediments would build up and spread into the adjacent bay would be difficult to predict; however, very low levels of hydrocarbons have been shown to cause numerous sublethal effects in many benthic, epibenthic, planktonic, and intertidal estuarine organisms, and there is no reason to expect anything different in Winyah Bay.

The data obtained during this study indicate that although Winyah Bay continues to support populations of shrimps, crabs, and fishes, the diversity and abundance of organisms is surprisingly low, especially in the upper bay. These observations suggest that present levels of stress may be adversely affecting the health and future of Winyah Bay as a functional estuary. The implications of the deterioration of Winyah Bay to commercial and recreational fisheries in the future are not good, and the consequences of increased petroleum-based energy development in this estuarine area could be serious and long-lasting. The following quote from the National Academy of Sciences report on petroluem in marine environments (1975; p. 86) provides an articulate conclusion to this report, and should be pondered by decision-makers concerned with future development in Winyah Bay:

> "The soluble fractions of petroleum probably are the most harmful to marine organisms. These undoubtedly make up the bulk of the oil that enters the coastal waters as co-product brines and refinery effluents. Such discharges, particularly when they occur in estuaries, may pollute the shallow water areas that serve as nursery areas for many coastal marine biota. These waters ordinarily are subject to extremes of temperature, and where tidal fluctuations are small, flushing of the bays and dispersal of wastes may be slow. These characteristics of estuaries may combine with the chronic introduction of oil wastes...to intensify biological effects.
>
> "In addition, the slow dispersal of oil in some estuaries can increase adsorption onto suspended particulate matter. When these suspended particulates are incorporated in the sediments, the exposure of benthic organisms to oil is increased. The high biological productivity of estuaries ensures the exposure of many organisms to the wastes, particularly in the sensitive stages of their life history. Synergistic interactions between extremes of temperature and salinity and oil may aggravate deleterious effects. Therefore, because they combine biological productivity with the most severe exposure to wastes, estuaries are most vulnerable to the serious effects of chronic oil pollution."

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